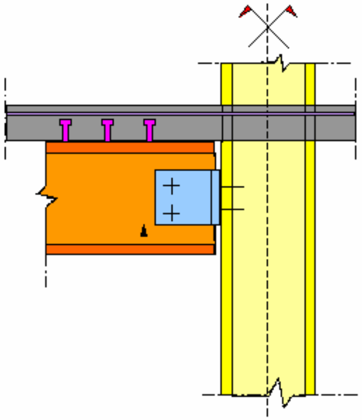
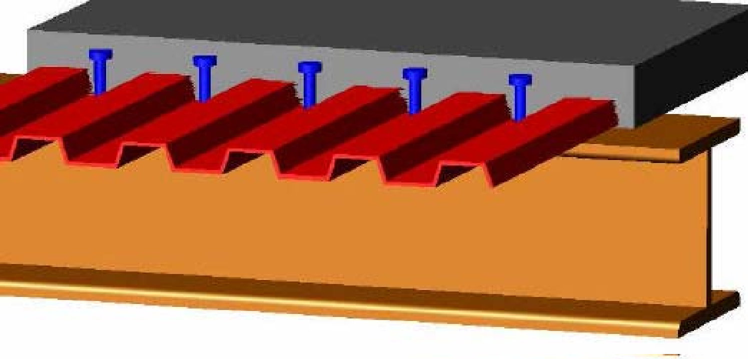


Dr. Seshu Adluri

Structural Steel Design
Composite Beams

Composite Construction and Cambering



Composite beams

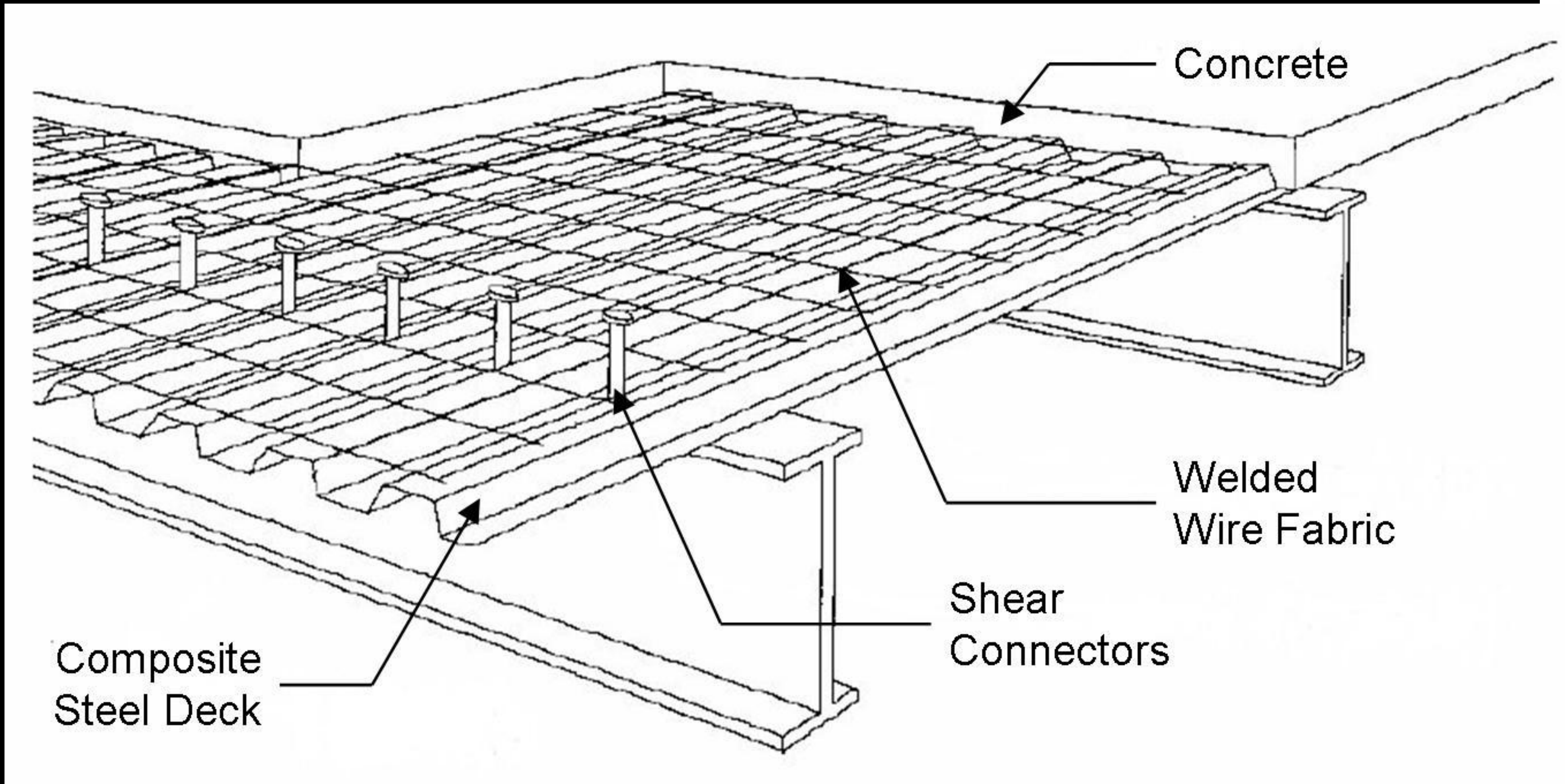
- In many buildings and bridges, it is common to have a concrete slab supported by steel beams. If the steel beams are connected to the concrete slab in such a way that the two act as one unit, the beam is called as composite beam.

- Composite beams are similar to concrete T-beams where the flange of the T-beam is made of concrete slab and the web of the T-beam is made of the steel section.
- Composite beam has the advantage that the concrete in the slab takes all or most of the compression (for which it is best suited), while the steel beam takes all the tension in the overall system.

AISC.org

Composite Construction

Introduction to Composite Construction



Adapted From (ASCE 2002)

- Composite construction refers to two load-carrying structural members that are integrally connected and deflect as a single unit
- An example of this is composite metal deck with concrete fill, steel filler beams, and girders made composite by using headed stud connectors

AISC.org

Multi-Storey Building

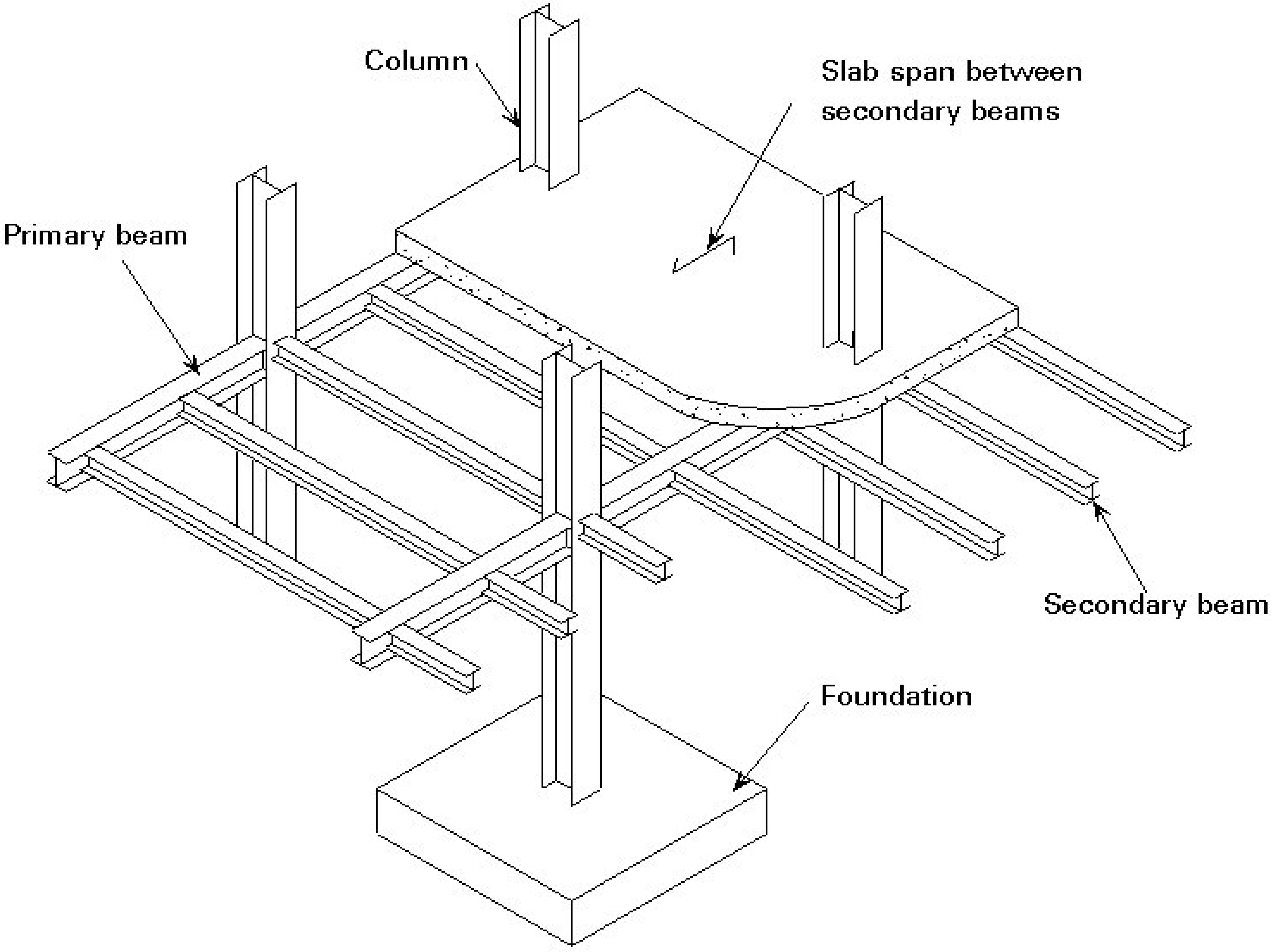
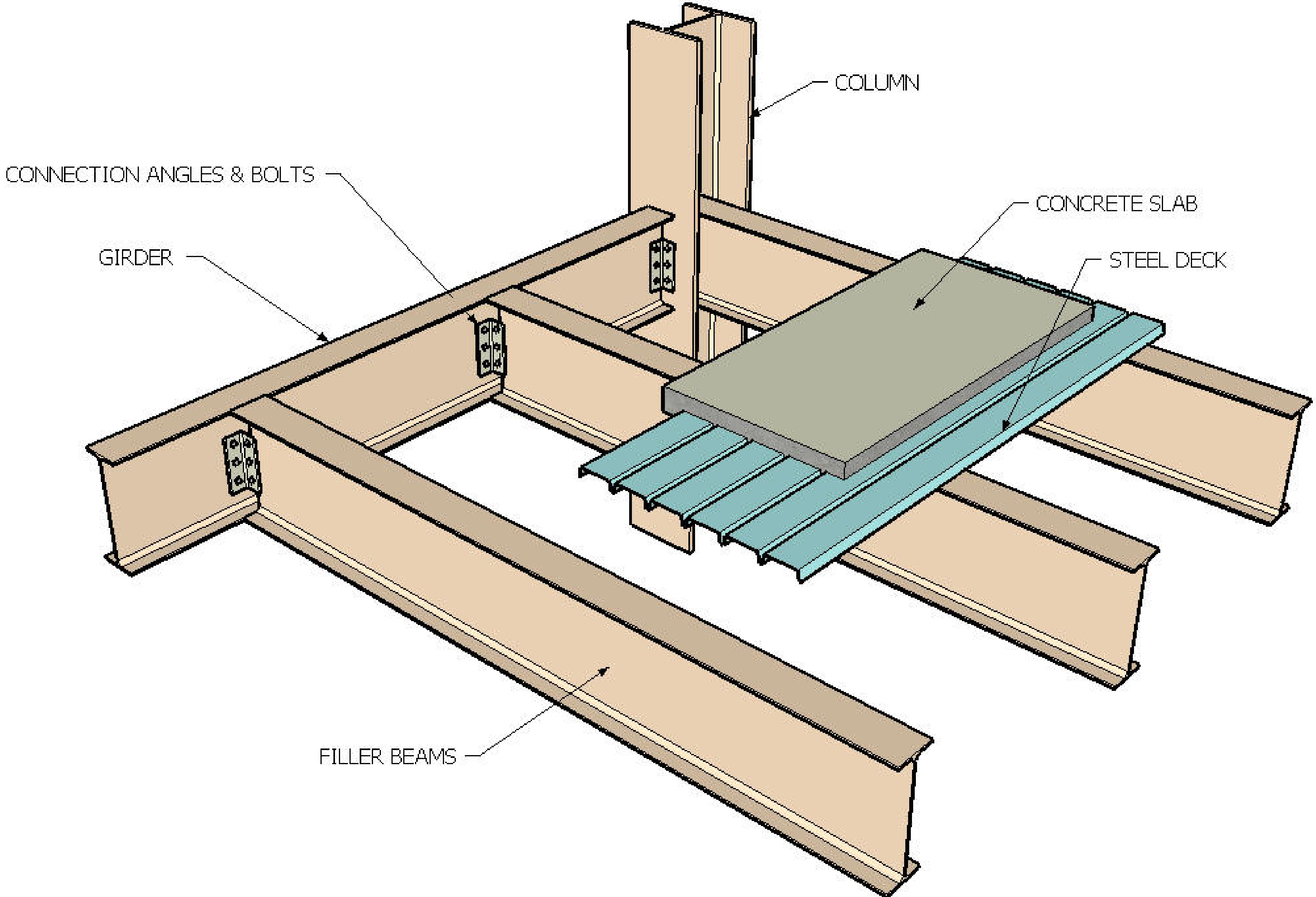


Figure 1 Typical structure

Composite Slab



Composite Slab

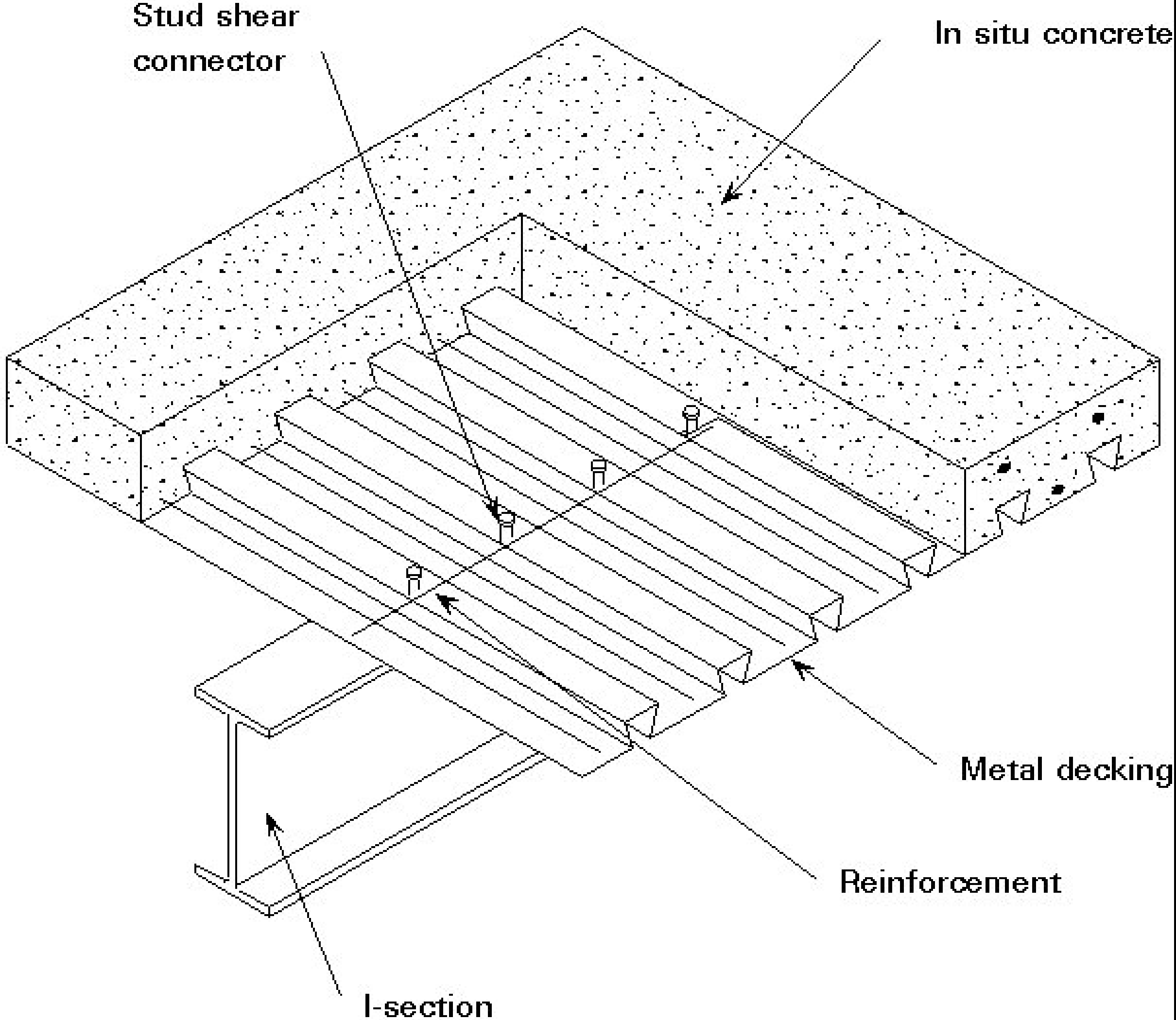
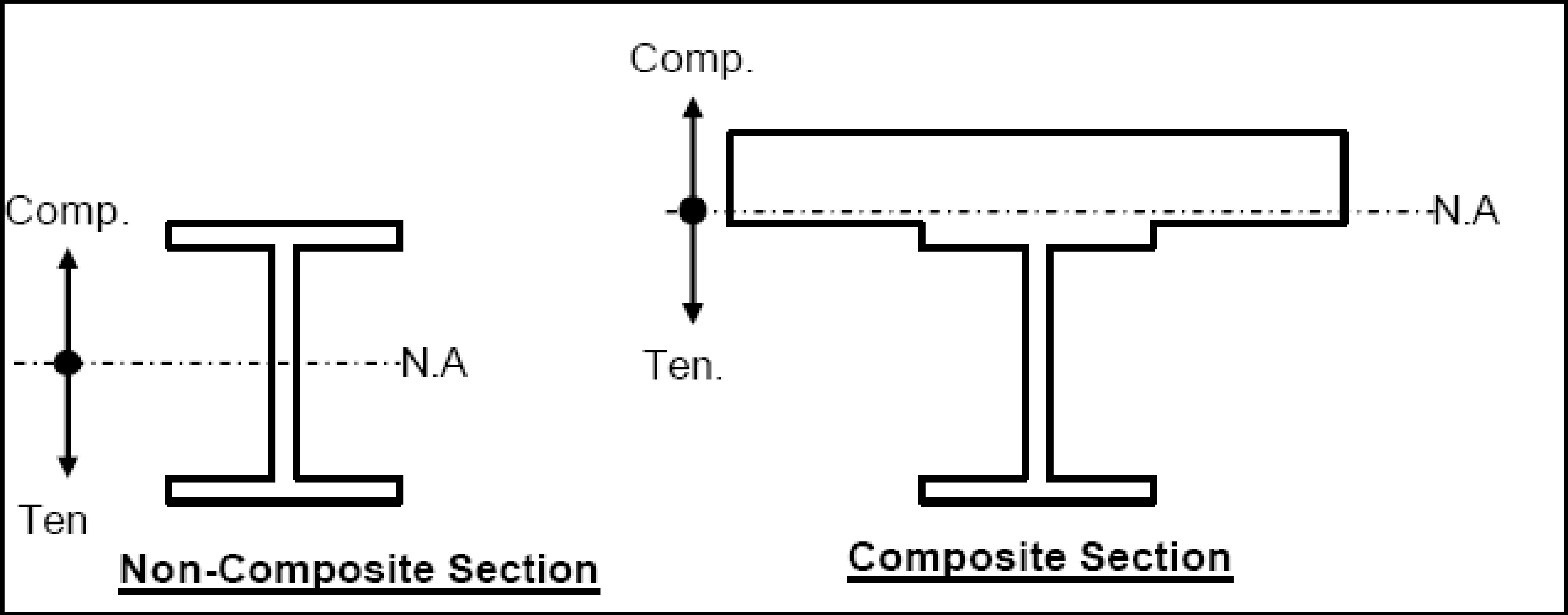
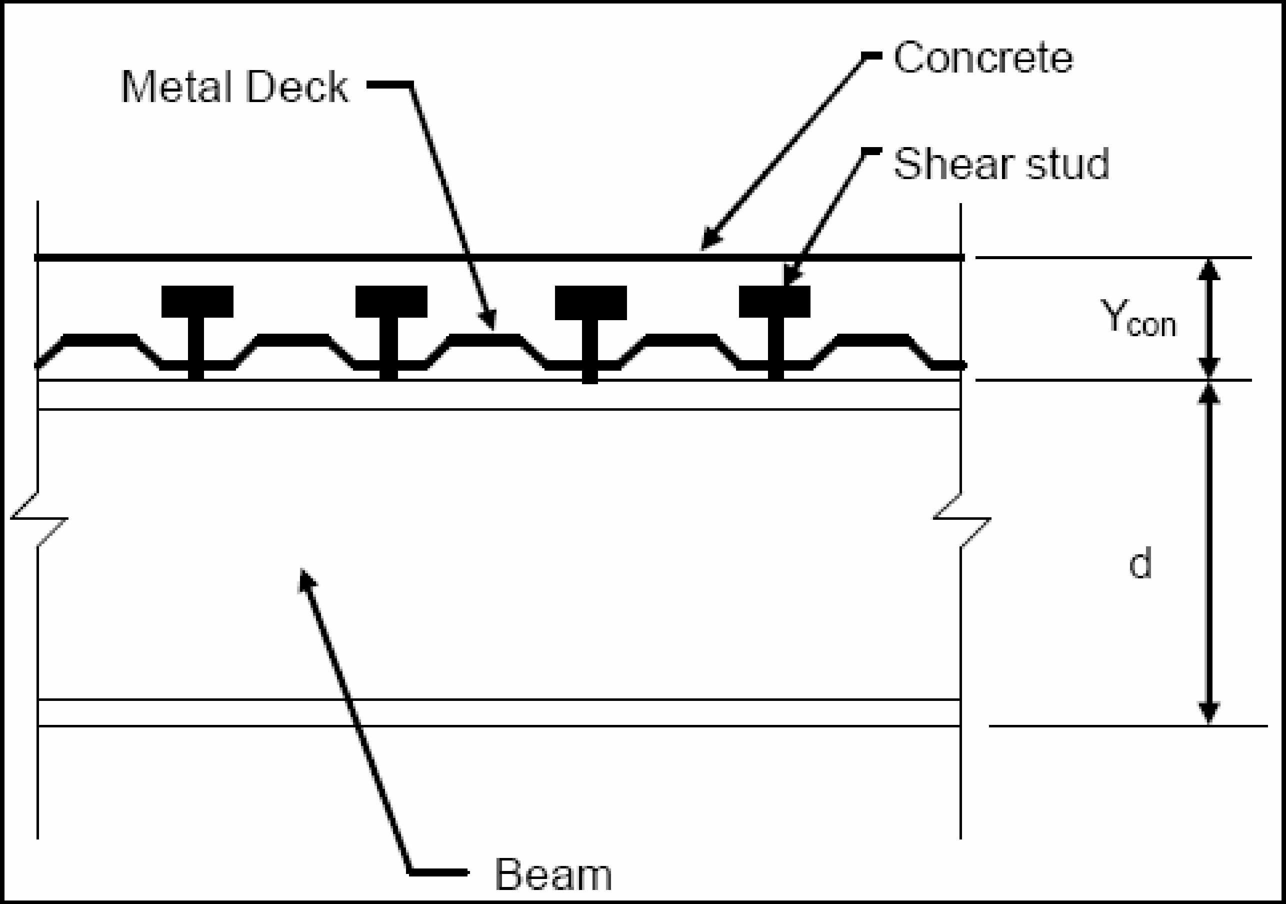


Figure 2 Concrete floor on steel decking

Composite beam



Composite beam



•

Introduction to Composite Construction

- A steel beam which is made composite by using shear connectors, composite metal decking and concrete is much stronger and stiffer than the base beam alone
- Composite floor systems are considered by many to be the highest quality type of construction
- This has become a standard type of construction selected by many architects, engineers, and developers (AISC 1991)

AISC.org

Advantages of Composite Construction

In a composite floor system the concrete acts together with the steel to create a stiffer, lighter, less expensive structure (Allen 1999)

AISC.org

Advantages of Composite Construction

AISC.org

Connecting the concrete to the steel beams can have several advantages:

- It is typical to have a reduced structural steel frame cost
- Weight of the structural steel frame may be decreased which may reduce foundation costs
- Reduced live load deflections
- Shallower beams may be used which might reduce building height
- Increased span lengths are possible
- Stiffer floors

Disadvantages of Composite Construction

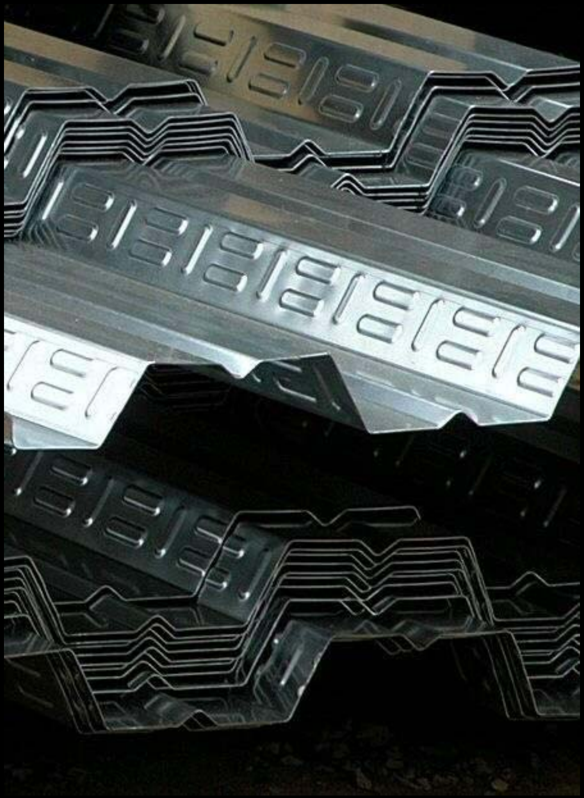
- The additional subcontractor needed for shear connector installation will increase field costs
- Installation of shear connectors is another operation to be included in the schedule
- A concrete flatwork contractor who has experience with elevated composite slabs should be secured for the job

AISC.org

MEMORIAL UNIVERSITY
Newfoundland & Labrador, Canada

FACULTY OF ENGINEERING & APPLIED SCIENCE

Metal Decking



- Composite decking works together with the concrete fill to make a stiff, light-weight, economical floor system
  - Compare the composite decking (above left), non-composite decking (above center), and the form decking (above right)
- Composite decking is available in various profiles and thicknesses

AISC.org

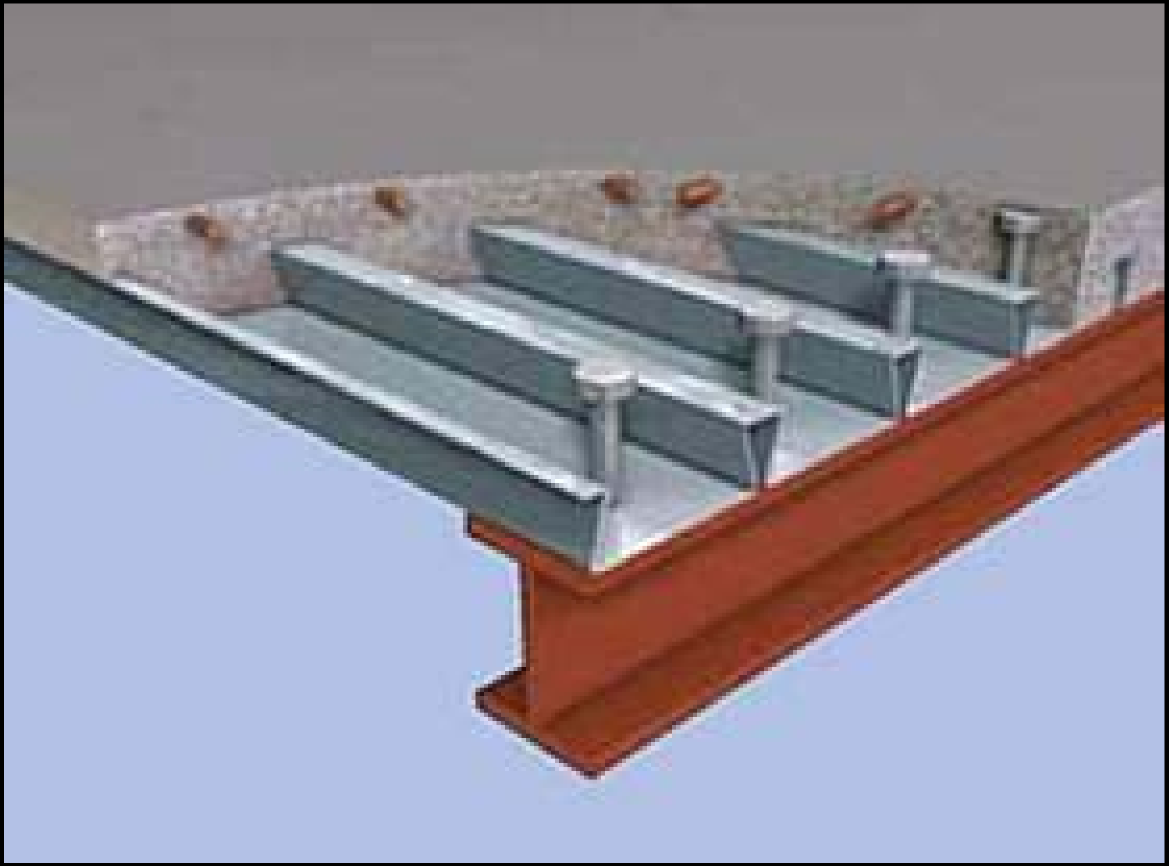
Composite Metal Decking

- Decking with deformed ribs (or embossed decking), as shown, is commonly used
- The deformations on the ribs allow for a stronger bond between the concrete and the decking

(ASCE 2002)

AISC.org

Composite Metal Decking

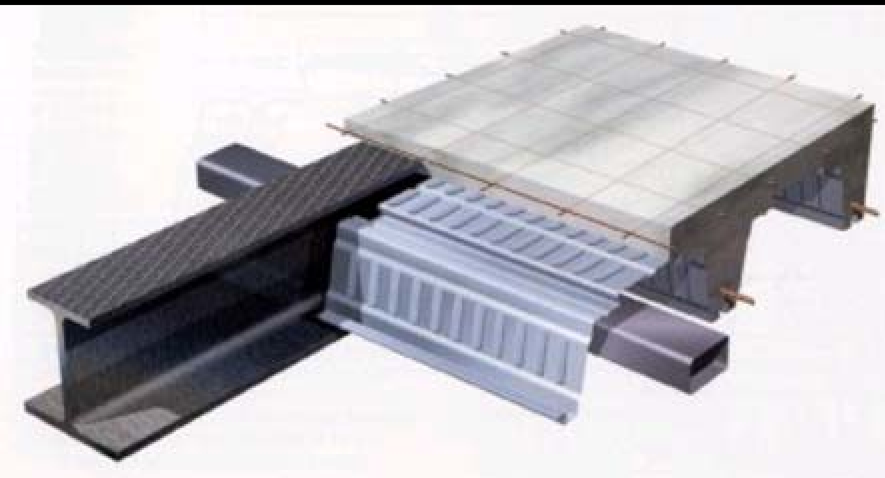


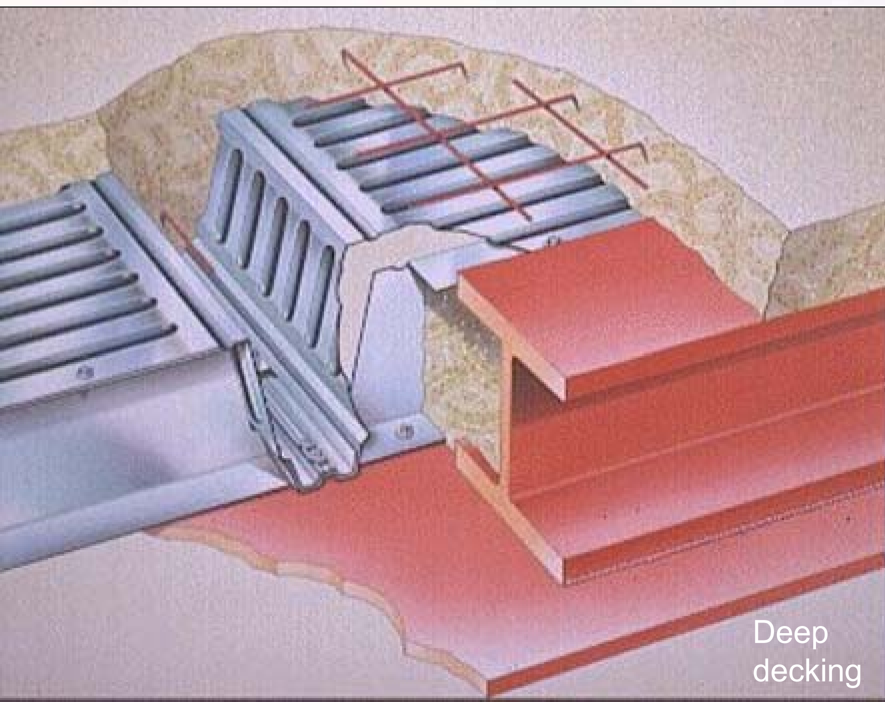
Less common styles of composite decking include:

- Decking with the ribs formed in a dovetail or fluted pattern (above)
- Decking with welded wire fabric welded to the ribs
- Decking with steel rods welded across the ribs

Image courtesy of Epic Metals Corporation

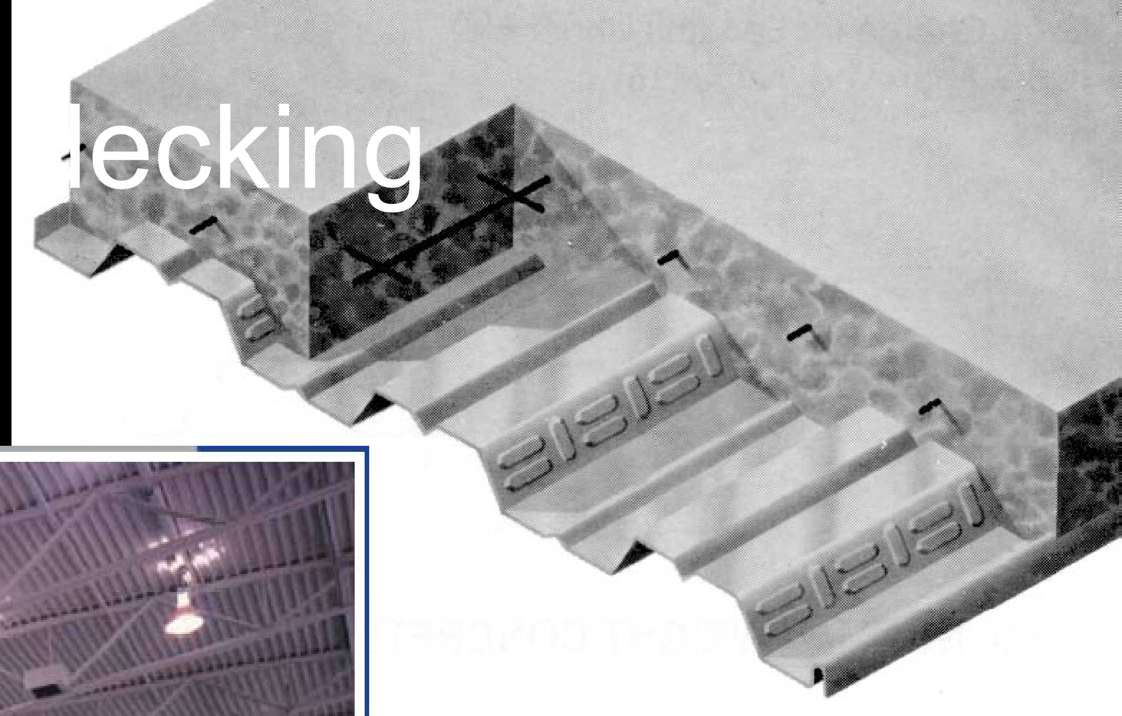
Metal deck





Deep decking

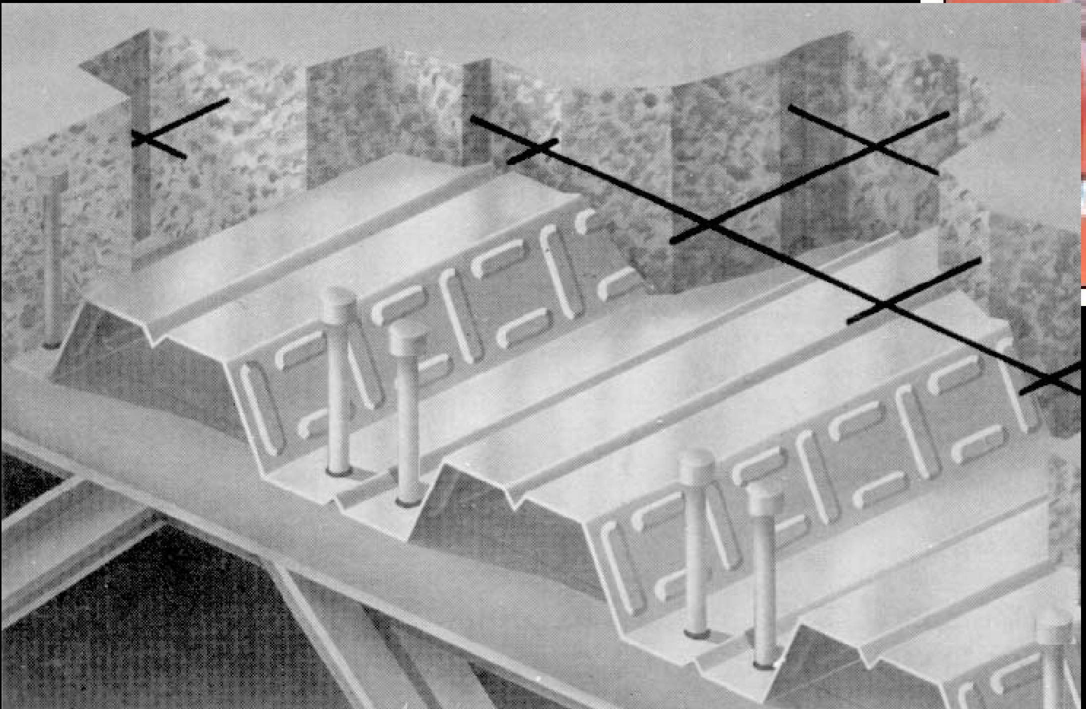
Metal decking



VULCRAFT

Composite slab with OWSJ

•



Installation of Decking

- Metal decking is placed on the structural steel at predetermined points in the erection sequence
- Metal decking may be installed by the steel erection contractor or a separate decking contractor

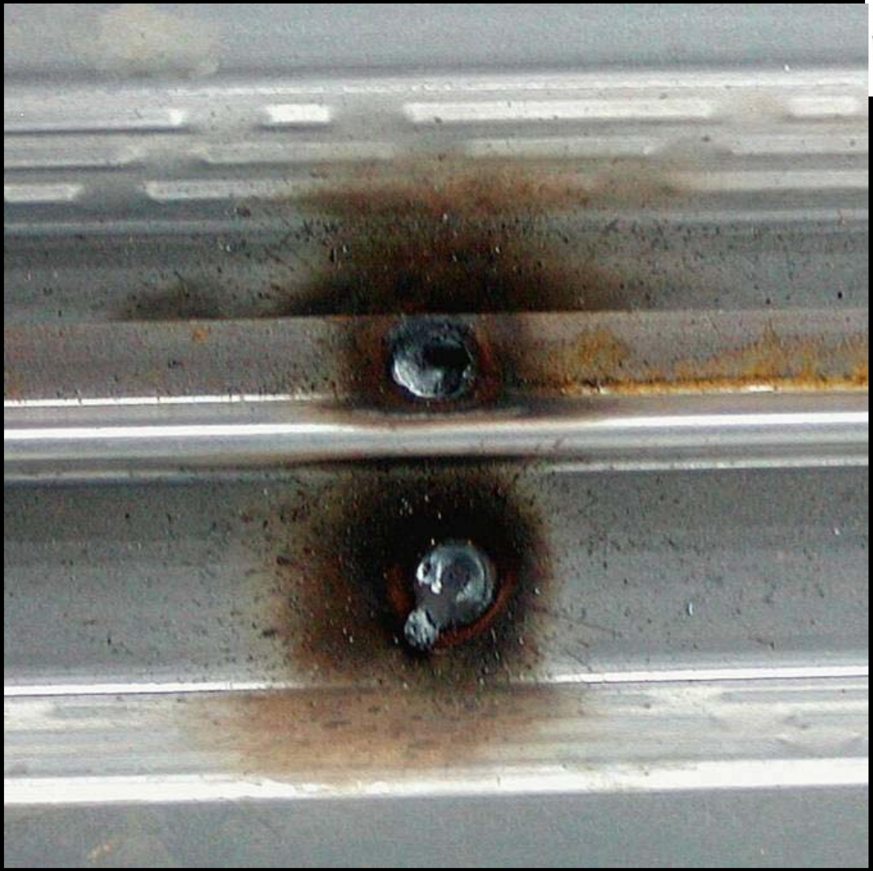
AISC.org

Installation of Decking

- Per the Occupational Safety & Health Administration Standard 1926.760(c) the decking crew may work in a controlled decking zone while placing and attaching the decking
- A controlled decking zone is an area in which initial installation and placement of metal decking may take place without the use of guardrail systems, personal fall arrest systems, fall restraint systems, or safety net systems and where access to the zone is controlled

AISC.org

Installation of Decking



- Puddle welds (above right) are commonly used to attach the decking to the structural steel below
- Daily output for a four person decking crew ranges from 2700 S.F. to 3860 S.F. per day depending on the depth and gauge of the decking (Means 2004)

AISC.org

Installation of Decking

- As an alternative to welding, powder actuated tools may be used to attach metal decking to structural steel
- Powder actuated tools use the expanding gases from a powder load, or booster, to drive a fastener
- A nail-like fastener is driven through the metal deck into the steel beam
- The powder actuated tool, powder load, and fastener must be matched to the thickness of the structural steel beam flanges

Images courtesy of Hilti Corporation

Shear Connectors

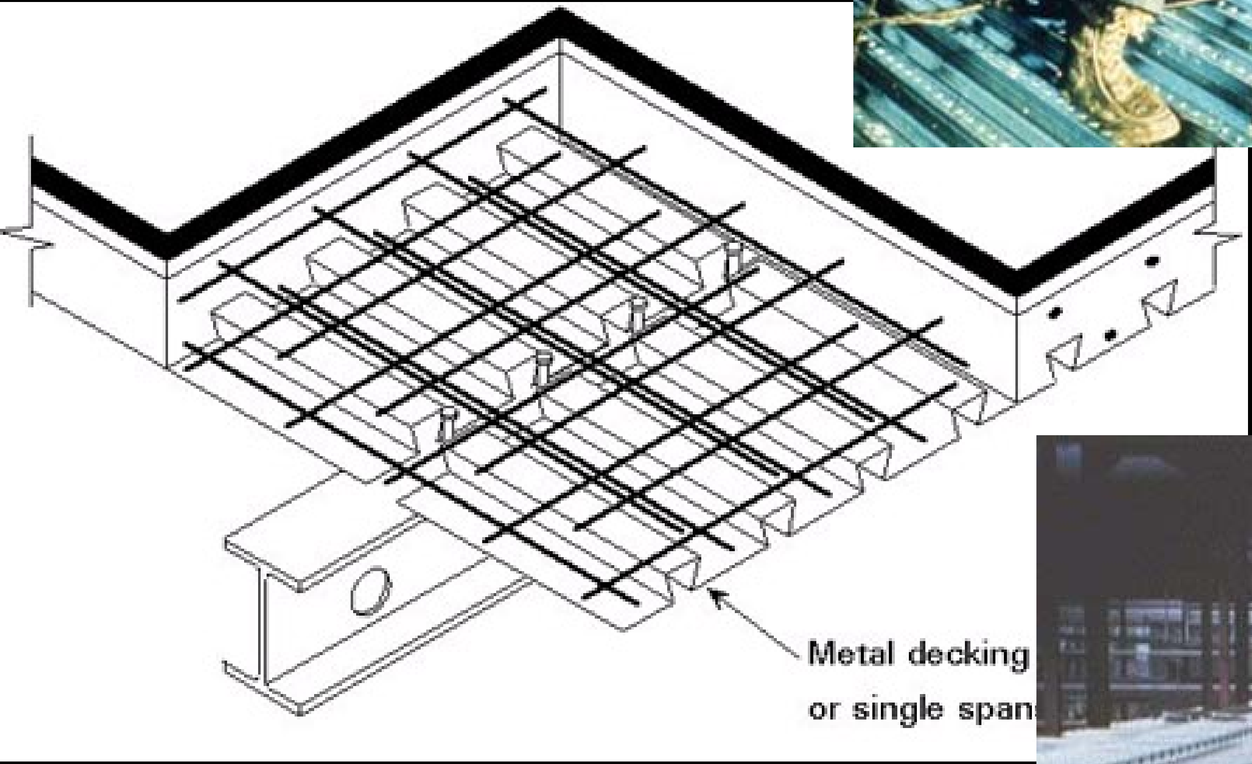
- Shear connectors are commonly referred to as “studs” or “shear studs” in the trade
- They are available in a range of sizes, materials, and grades
- Headed studs (as shown) are most commonly used
- Other, less common options for shear connectors include hooked studs or pieces of C-channel

Shear Connectors

- Depending on the welding process used, the tip of the shear connector may be placed in a ceramic ferrule (arc shield) during welding to retain the weld
- Shear connectors create a strong bond between the steel beam and the concrete floor slab which is poured on top of the metal decking
- This bond allows the concrete slab to work with the steel beams to reduce live load deflection

AISC.org

Shear



Shear studs

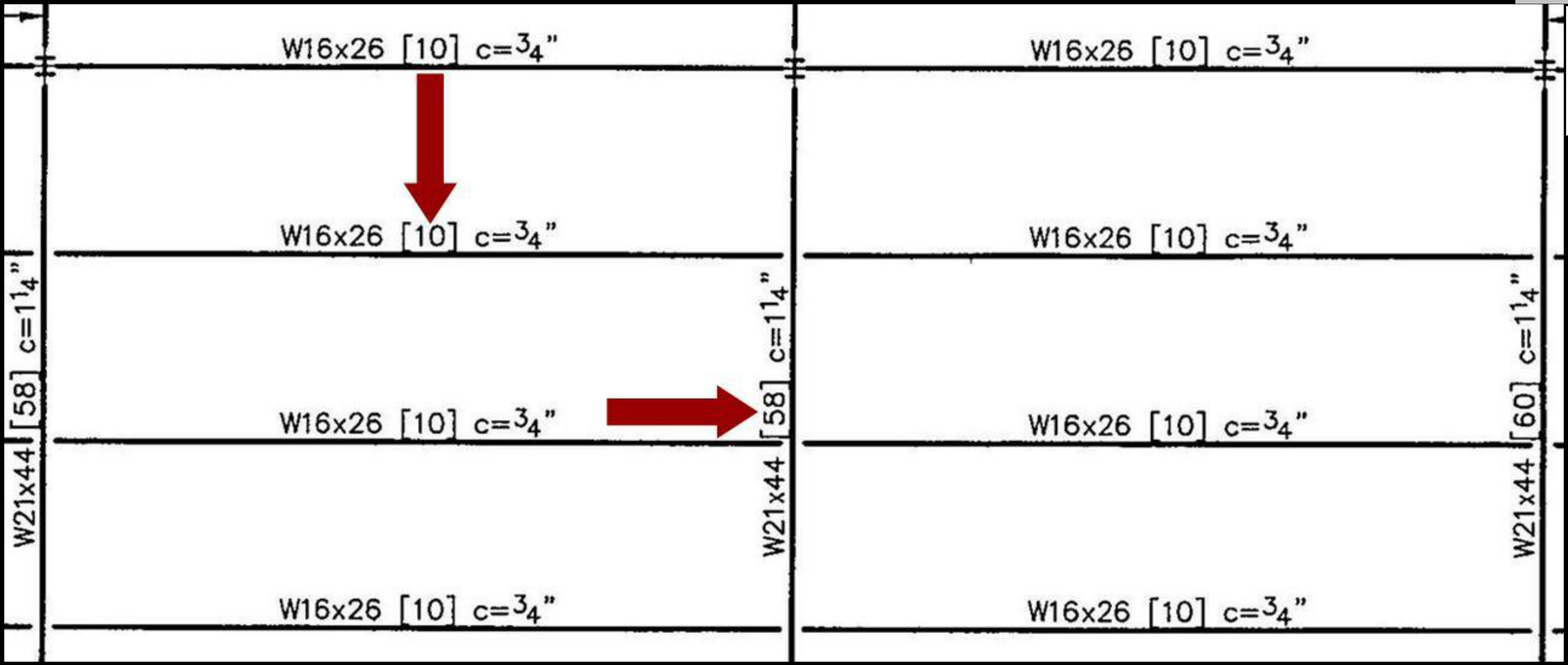
- Shear studs without a deck

Installation of Shear Connectors

- Shear connectors are installed after the decking is in place
- Shear connectors may be installed by the steel erection contractor or a specialty shear connector installer
- The welding equipment required for installation is provided by the shear connector installer
- Daily output for shear connector installation averages about 1000 per day depending on the size of the connectors (Means 2004)

AISC.org

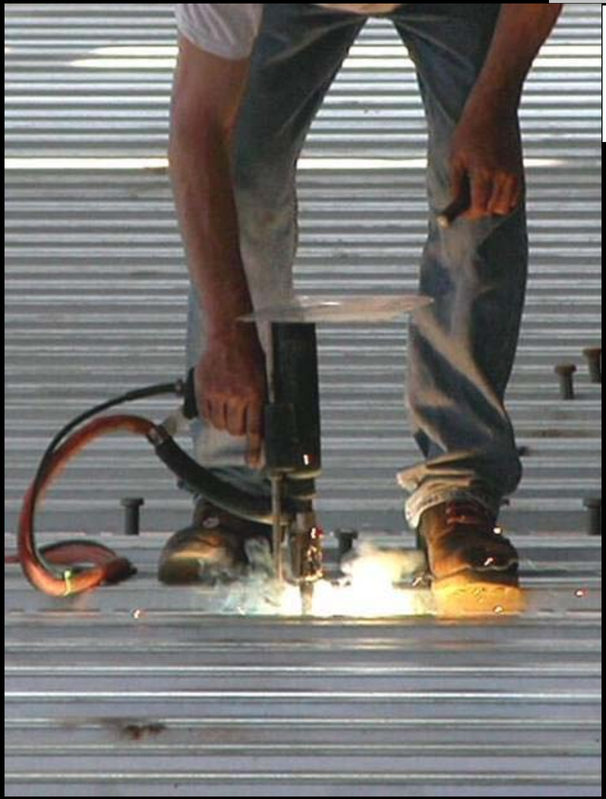
Installation of Shear Connectors



- The bracketed numbers on the drawing above give the number of shear studs to be installed at an even spacing on the respective beam
  - When spacing is not uniform it will be indicated on the plan
- Specified spacing of the shear connectors is an important part of the composite design and must be adhered to
- Minimum spacings keep concentrations of compressive forces from occurring at the stud locations
- Maximum spacings help avoid separation of the slab from the beam and guarantee the uniform transfer of shear force (RLSD 2002)

AISC.org

Installation of Shear Connectors



- The electrical arc process is commonly used for stud welding
  - An arc is drawn between the stud and the base metal
  - The stud is plunged into the molten steel which is contained by the ceramic ferrule
  - The metal solidifies and the weld is complete
- The ferrules are removed before the concrete is poured

(ASCE 2002, AWS 2004)

AISC.org

Installation of Concrete

- Concrete is installed by a concrete contractor on top of the composite metal decking, shear connectors, and welded wire fabric or rebar grid (crack control reinforcing)
- Pumping is a typical installation method for concrete being placed on metal decking
- 10,000 to 15,000 sq. ft. of concrete slab may be installed per day depending on slab thickness and crew size (Ruddy 1986)

AISC.org

Installation of Concrete

- There is an art to the placement of concrete on metal deck and structural steel
- The work, unless shoring is used, must be executed on a deflecting surface
- An experienced concrete contractor should be employed for this work
  - Concrete should be deposited over supporting members first, then spread toward the deck midspans
  - The accumulation of a deep pile of concrete must be avoided

(AISC 2003, ASCE 2002)

AISC.org

Installation of Concrete

- Concrete construction joints should be located over the beam or girder webs
- Sometimes this is not possible and the joint is located near the decking midspan
    - Shoring should be placed beneath the construction joints until the concrete on both sides of the construction joint has reached 75% strength
        - This avoids a bond failure between the hardened concrete and the metal deck when the adjoining concrete is placed

    (ASCE 2002)
- Placement of construction joints must be reviewed by the Engineer of Record

AISC.org

Installation of Concrete

- The contractor must be aware of camber in the beams and the expected deflections
- Consultation with the structural engineer may be necessary
- As the concrete cures it forms a connection with the composite metal decking and shear studs
- The composite floor system is now complete

(AISC 2003)

AISC.org

Quality Control

- The shear connectors used in composite construction require specific inspections and quality control
- Testing procedures are specified in the contract documents or by a local building authority
- AWS D1.1 – Structural Welding Code – Steel, Section 7: Stud Welding (AWS 2004) specifies the tests and inspections for shear studs

AISC.org

Quality Control

- As described in the AWS code (AWS 2004), jobsite conditions may exist that prohibit or delay the stud welding operation
- The primary issues affecting the installation of the shear connectors are:
  - Moisture on the decking or ferrules
  - Moisture between the decking and the steel beam below
  - A steel temperature below 0° F
- In the pictures above, a torch is being used to remove snow (left) from the areas where shear studs are to be installed (right)

AISC.org

Quality Control

- Required quality control procedures for shear connectors include pre-production tests and fabrication inspections
  - Pre-production testing is performed by the shear stud installer at the beginning of each work shift and includes the following steps:
    1. Weld two sample studs
    2. Inspect for flash
    3. Perform bending test
    4. Equipment settings are recorded
  - The stud installer performs visual fabrication inspections as studs are installed
  - Other testing may be specified or may be necessary if all visual inspections are not passed (SIN 1998)

AISC.org

Cost Impacts of Composite Construction

When used appropriately, typical overall building costs will be less for composite construction than non-composite construction

AISC.org

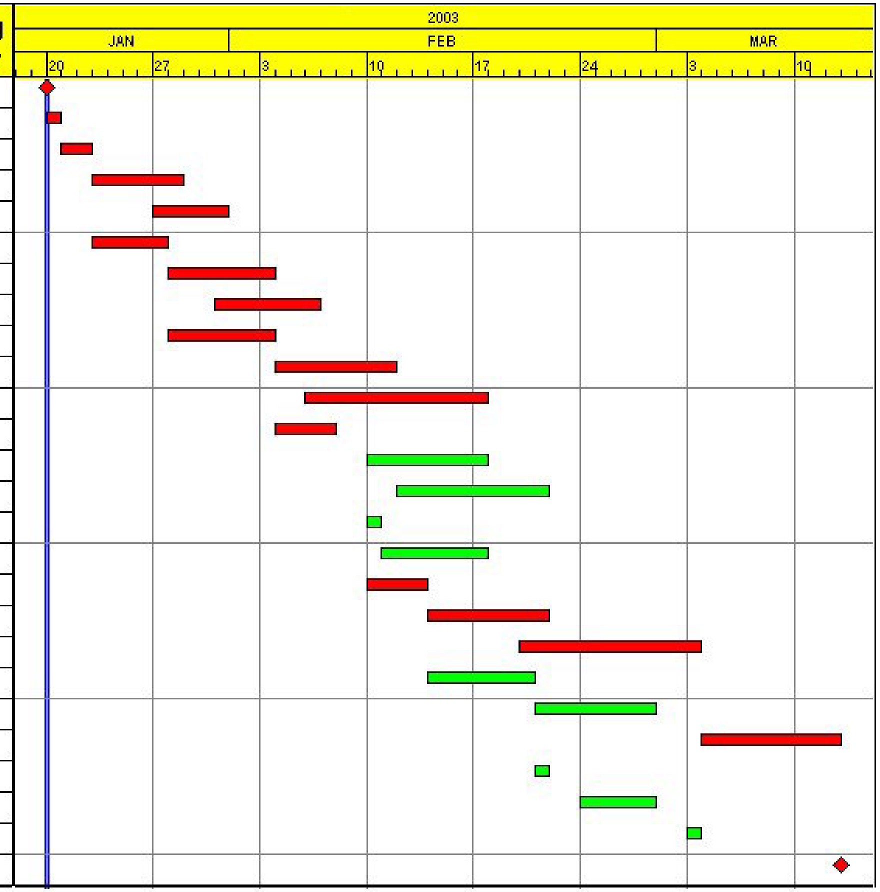
Cost Impacts of Composite Construction

- The U.S. national average installation cost for shear studs ranges from \$1.15 to \$1.72 per connector (Means 2004)
- A cost comparison should be made between the reduced structural steel cost and the additional shear connector cost when determining whether or not to use composite construction

AISC.org

Scheduling of Composite Construction

Activity ID	Activity Description	Orig Dur
1200	Structural Steel Erection Start	0
1205	Crane Set Up	1
1210	Hoisting Sequence 1	2
1215	Bolt up and Detail Work Sequence 1	4
1220	Deck and Studs Sequence 1	5
1225	Hoisting Sequence 2	3
1230	Bolt up and Detail Work Sequence 2	5
1235	Deck and Studs Sequence 2	5
1240	Hoisting Sequence 3	5
1245	Bolt up and Detail Work Sequence 3	6
1250	Deck and Studs Sequence 3	8
1255	Hoisting Sequence 4	4
1260	Bolt up and Detail Work Sequence 4	6
1265	Deck and Studs Sequence 4	8
1270	Plumbing Up Sequences 1-4	1
1275	Final Bolt Up Sequences 1-4	5
1280	Hoisting Sequence 5	4
1285	Bolt up and Detail Work Sequence 5	6
1290	Decking and Studs Sequence 5	8
1295	Hoisting Sequence 6	5
1300	Bolt up and Detail Work Sequence 6	6
1305	Decking and Studs Sequence 6	7
1310	Plumbing Up Sequences 5-6	1
1315	Final Bolt Up Sequences 5-6	5
1320	Crane Demobilization	1
1325	Structural Steel Erection Finish	0



- The duration for the installation of shear studs is project dependent and should be considered on a project by project basis
- Shear stud installation usually has little or no impact on the overall project schedule

Scheduling of Composite Construction

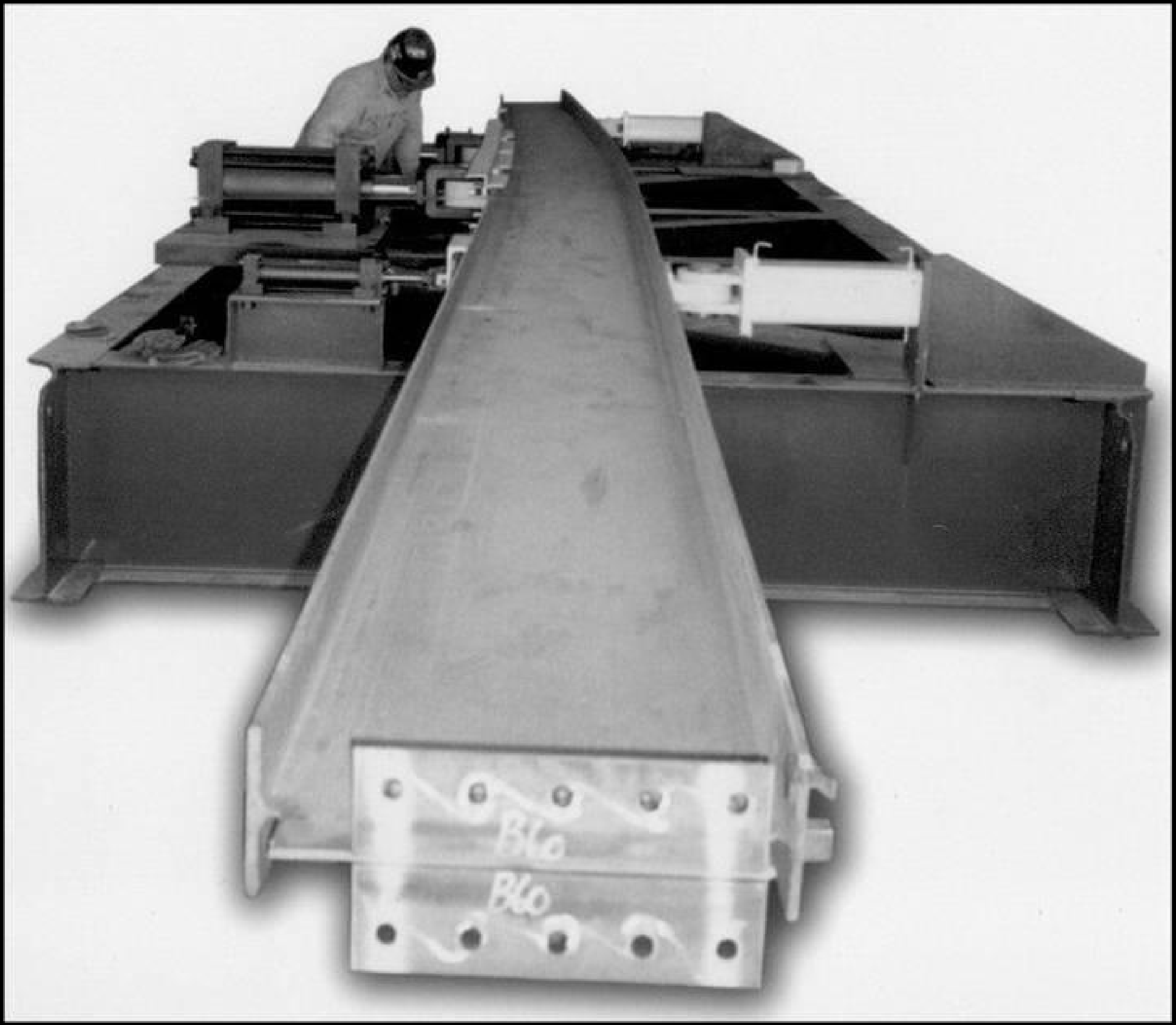
- It may be possible, depending on the size of the structure and the sequencing of erection and decking, to install the shear studs as erection proceeds
- It may also be possible to have a majority of the shear connectors in place and begin placing concrete for the floor slabs while structural steel is being erected in another area of the building
- On the structure shown above part of the composite first floor slab was placed while erection of the structural steel for the third floor proceeded

AISC.org

Cambering

Image courtesy of CAMBCO Inc.

Introduction to Cambering



Cambering is the process of creating an intentional slight curvature in a beam

Image courtesy of CAMBCO Inc.

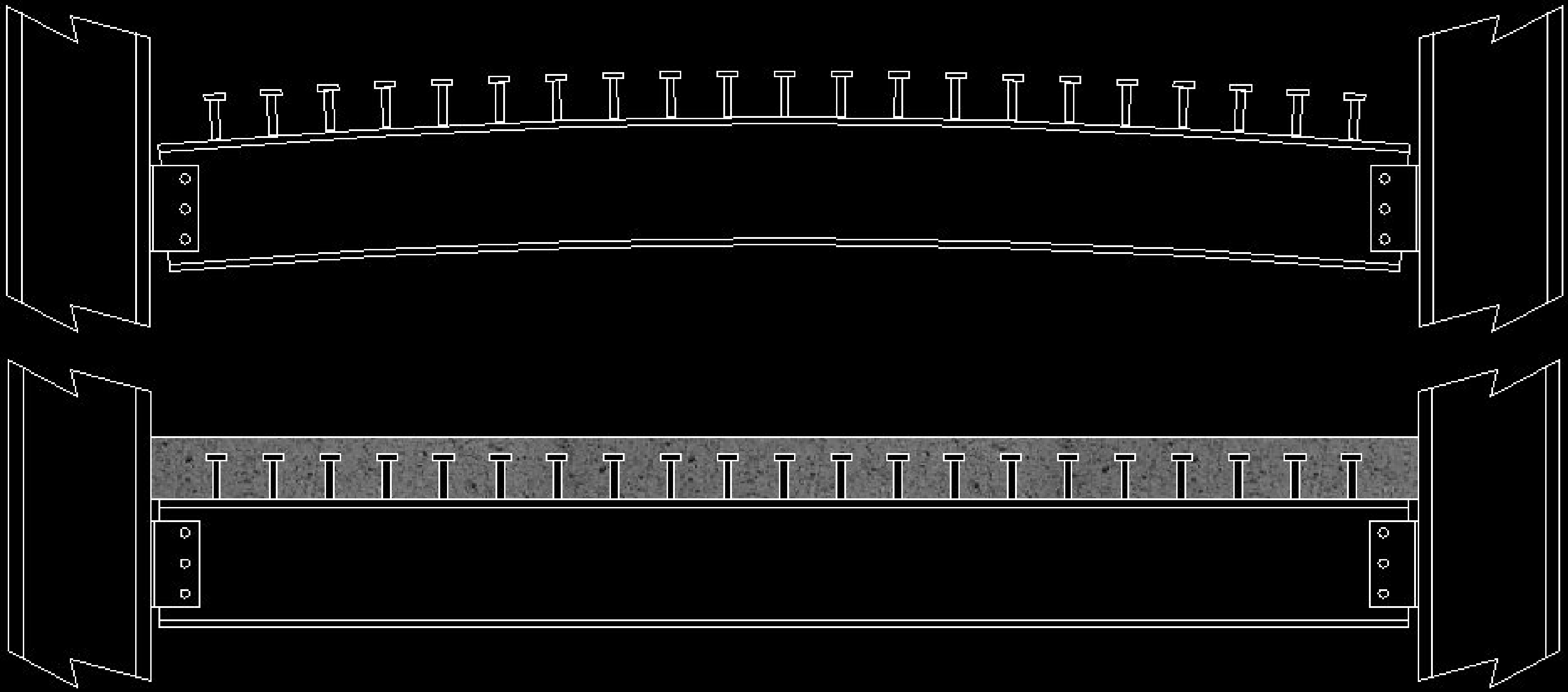
AISC.org

Introduction to Cambering

- Camber in a beam can be designed to compensate for either:
  - A certain percentage of the dead load deflection
  - The full dead load deflection
  - The full dead load deflection as well as a percentage of the live load deflection (Ricker 1989)
- Camber is usually designed to compensate for deflections caused by pre-composite dead loads

AISC.org

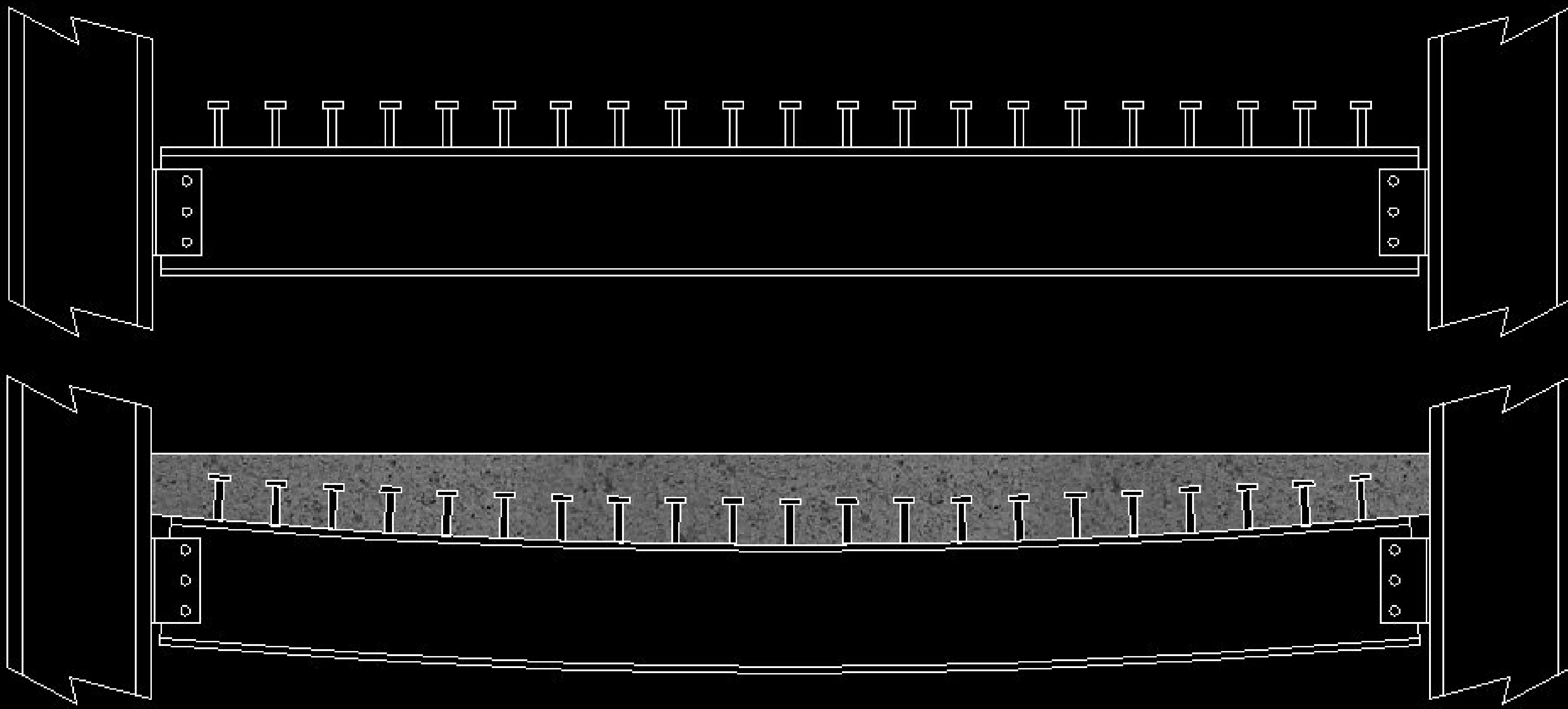
Advantages of Cambering



- Supporting beams will deflect under the load of concrete being placed
- This deflection can be exaggerated in a composite floor system where the full strength of the system is not achieved until the concrete has cured
- Cambered beams (top diagram above) should deflect to a straight line (bottom diagram above), if load and deflection are predicted accurately and camber equals deflection
  - This allows the floor slab to be flat while maintaining a consistent thickness (Larson and Huzzard 1990)

AISC.org

Advantages of Cambering



- If beams are not cambered (top diagram above) the deflection under the load of the wet (plastic) concrete will result in a ponding effect in the concrete (bottom diagram above)
- To create a flat floor in this situation the concrete will need to be thicker at the center of the bay where the deflection is the greatest
- The volume of concrete used will typically be 10-15% more than if the floor is a constant thickness (ASCE 2002)

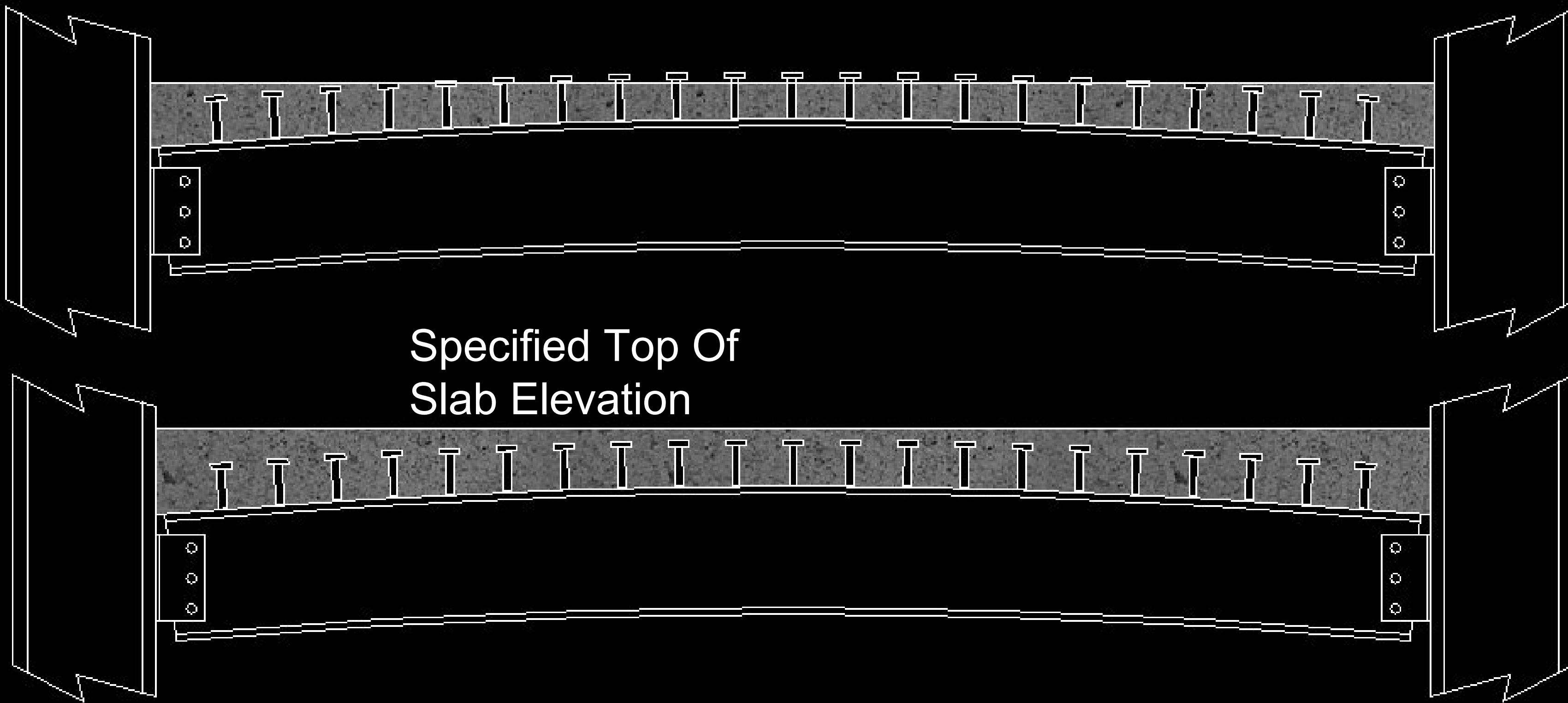
AISC.org

Disadvantages of Cambering

- The use of cambered beams will, to a certain degree, be limited by other aspects of the design for a structure
- Due to the complexity in detailing, fabrication, and fit-up associated with moment connections (above left), camber should not be used in moment connected beams
- Beams with simple framing connections (above right) may be cambered because the end rotational resistance of a simple connection is small in comparison to that of a moment connection

AISC.org

Disadvantages of Cambering

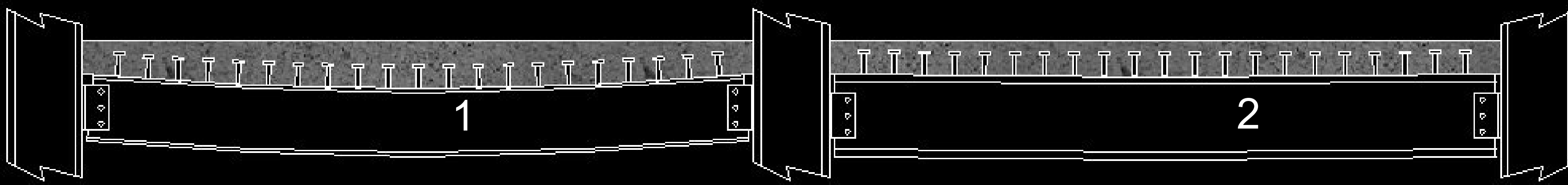


- The processes used to create camber in beams as well as the actual deflections under load of cambered beams are not exact
- Care needs to be taken in the specification and fabrication of camber to ensure that a beam, once in place and under load, will perform within tolerances
- Levelness and consistent floor thickness can be a problem (ASCE 2002)
- The diagrams above show two possible results of cambered beams not deflecting as predicted under the load of the wet (plastic) concrete

1. Stud heads are exposed
2. Top of slab elevation out of tolerance

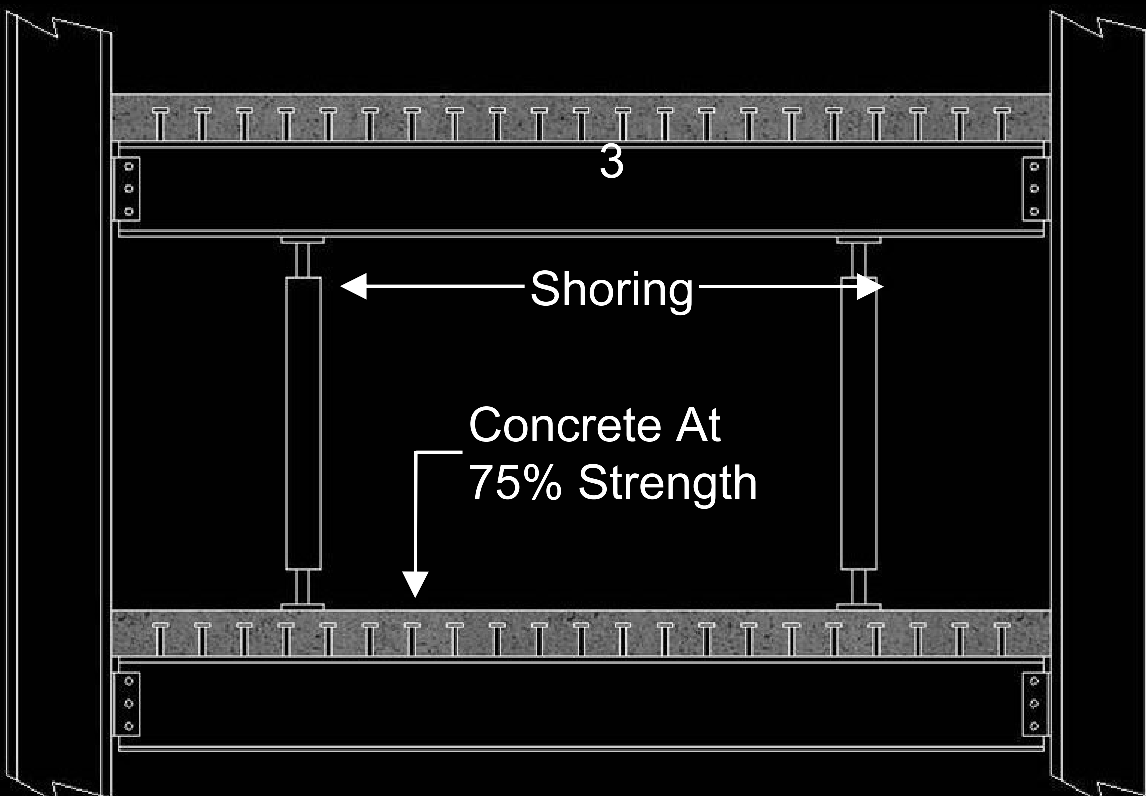
AISC.org

Alternatives to Cambering



Alternative methods for achieving a level floor slab without using cambered beams include:

1. Pouring a slab of varying thickness over deflecting beams
2. Using over-sized beams to minimize deflection
3. Shore the beams before placing the concrete



(Larson and Huzzard 1990)

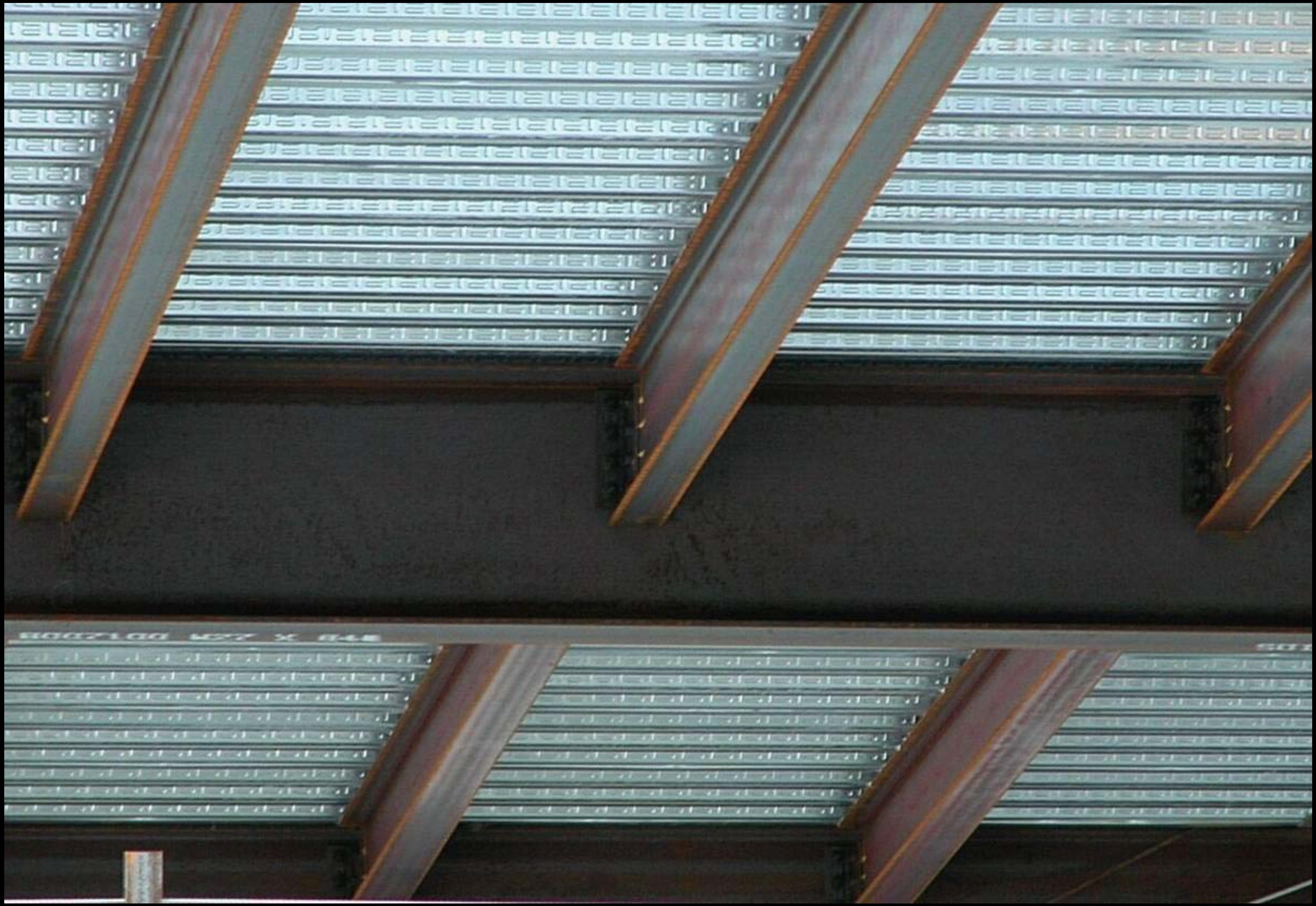
AISC.org

Shoring

- Shoring may be used in lieu of cambering
- The construction documents must specify the use of shoring
- There are several advantages to using shoring:
  - Lighter floor beams may be used
  - Cambers do not need to be designed or fabricated
  - Less beam deflection allows for better control of the slab thickness
  - Shoring can accommodate a contractor's special loading requirements

AISC.org

When to Camber



- Girder Beams
- Members with uniform cross section
- Filler Beams
- Composite Floor Beams

(Ricker 1989)

AISC.org

When Not to Camber

- Cantilevered Beams (above left)
- Crane Beams
- Moment Connected Beams
- Braced Beams (above right)
- Spandrel Beams (above right)

(Ricker 1989)

AISC.org

When Not to Camber

- Beams with moment connections (above left)
- Beams with non-symmetrical loading
- Beams under 20 feet in length (above right)
- Beams with end plate connections

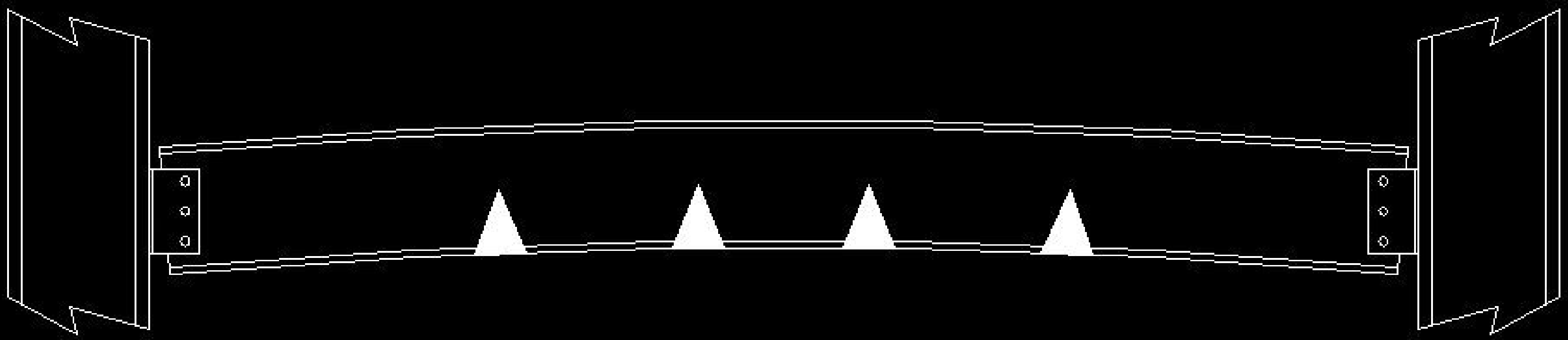
(Ricker 1989)

Heat Cambering

- Beams may be cambered by applying heat to small wedge-shaped areas at specific increments along the beam (Ricker 1989)
- The beam is placed upside down on supports so the “bottom” flange can be heated
- The heated flange expands under the heat and contracts as it cools
- Camber is induced in the opposite side of the beam as the heated flange cools
- Advancing this slide will begin an animation which shows the expansion and contraction that occurs in a heat cambered beam

The animation will repeat after several seconds

Installation of Heat Cambered Beams



- A heat cambered beam should be erected with the heat marks on the bottom side of the beam (see top diagram above)
  - This places the beam in a camber up (or concave down) orientation
- Heat marks can be seen on the beams in the bottom picture above

AISC.org

Cold Cambering

- Cold cambering methods are more widely used and generally more economical than heat cambering
- The beam is mounted in a frame and force from a ram(s) is used to bend the beam to create camber

(Ricker 1989)

Image courtesy of CAMBCO Inc.

Creating Camber

- Cambering is most commonly done at the fabricator's shop after the connections are fabricated (AISC 2000)
- The fabricator may mark cambered beams to ensure proper installation

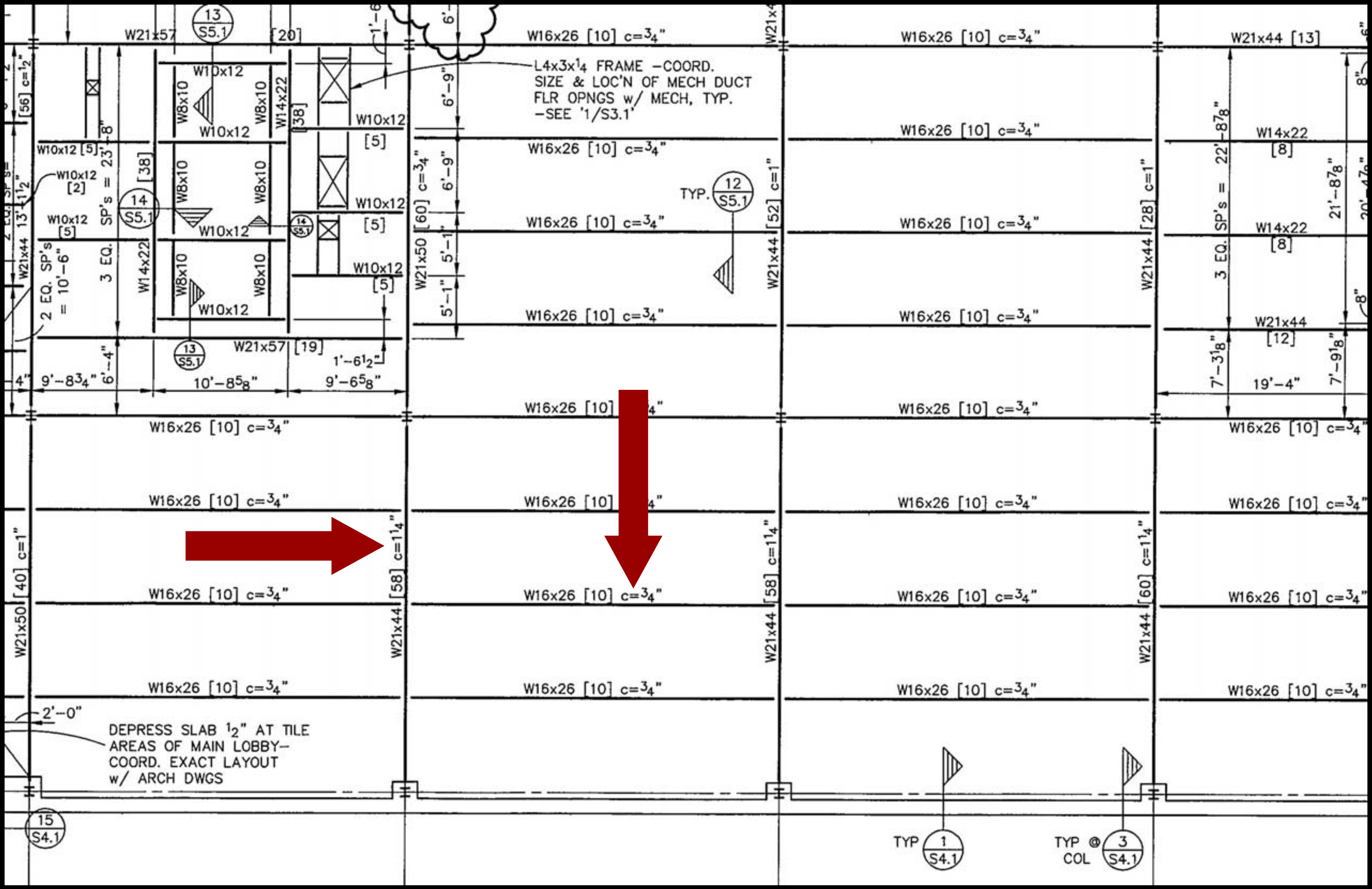
AISC.org

Natural Mill Camber

- Natural mill camber, which is a slight camber present in a beam when it is received from the mill, will exist in most beams
- If the natural mill camber is at least 75% of the specified camber, no further cambering by the fabricator is required
- If camber is not specified, the beams will be fabricated and erected with any natural mill camber oriented up (or concave down) (AISC 2000)

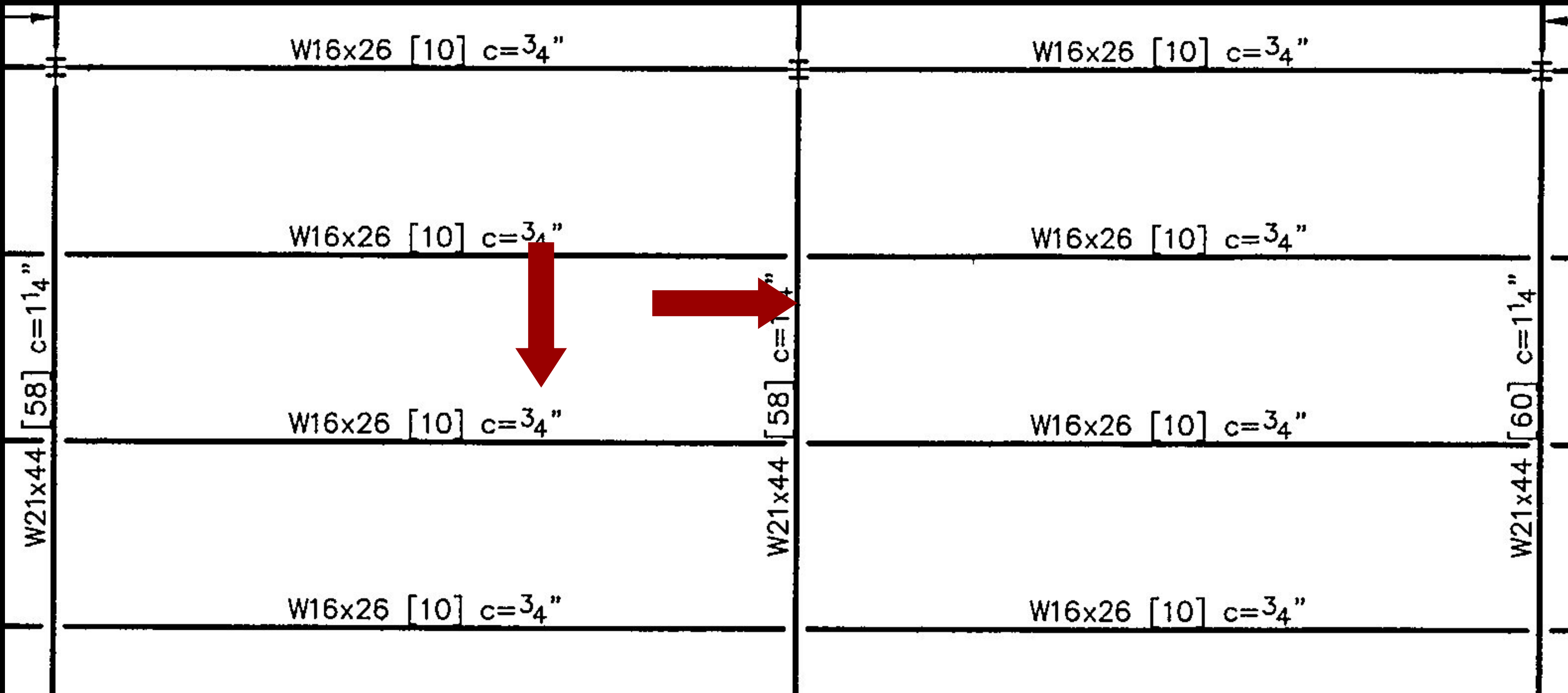
AISC.org

Cambered Beams on Structural Plans



Cambered beams should be clearly marked on the structural plans (AISC 2000)

Cambered Beams on Structural Plans



- The structural plan above shows which beams are cambered
- The amount of camber is indicated for each cambered beam
    - c=3/4" indicates that the beams are cambered 3/4" at the center
    - c=1 ¼" indicates that the girders are cambered 1 ¼" at the center

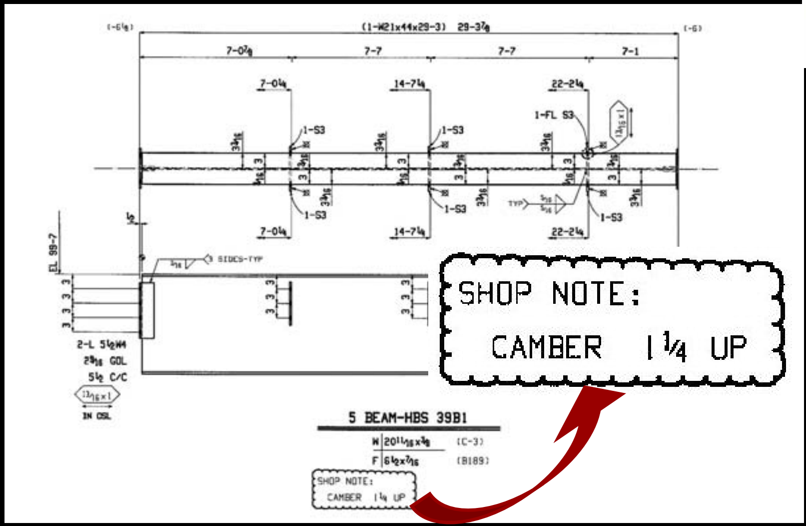
AISC.org

Installation of Cambered Beams

- The installation of cambered beams is similar to that of other structural steel members
- No additional tooling, equipment, or hardware should be required

AISC.org

Quality Control



- Per the AISC Code of Standard Practice "camber shall be measured in the Fabricator's shop in the unstressed condition." (above left)
  - The amount of camber specified on the shop drawing (above right) is for the beam center line in an unstressed or unloaded condition
- Tolerances for camber are specified in the AISC Code of Standard Practice:
  - Members 50 feet or less in length = minus 0" and plus 1/2"
  - Members over 50 feet the plus tolerance is increased by 1/8" for every 10 feet over 50 feet

(AISC 2000)

AISC.org

Quality Control

- It is possible for all or part of the induced camber to come out of a beam during shipment to a jobsite
- This is acceptable under the AISC Code of Standard Practice (2000), but the fabricator's quality control procedure should provide verification that the specified camber was measured in the shop

AISC.org

Cost of Cambering

- Cambered beams require additional fabrication resources which will make them cost more than non-cambered beams
- The additional cambering cost should be compared with
  - Cost of additional concrete due to “ponding”
  - Cost of using shored construction
  - Cost of using a heavier section that does not need to be cambered

Image courtesy of CAMBCO Inc.

Cost Savings from Cambering

- The cost to camber beams may be less than the alternatives
- A cost comparison can reveal the savings associated with the use of cambered beams
- Larson and Huzzard (1990), in their study of cambered beams and uncambered beams found a cost savings of approximately 4%
    - A 30’ x 30’ bay size was used
    - Filler beams were spaced at 10’ o.c.

AISC.org

Impacts on the Schedule

- There will be an increase in fabrication duration for structural steel to account for time required to create camber in beams
- The amount of time required to create camber is dependent on a fabricator's internal scheduling and fabrication methods

AISC.org

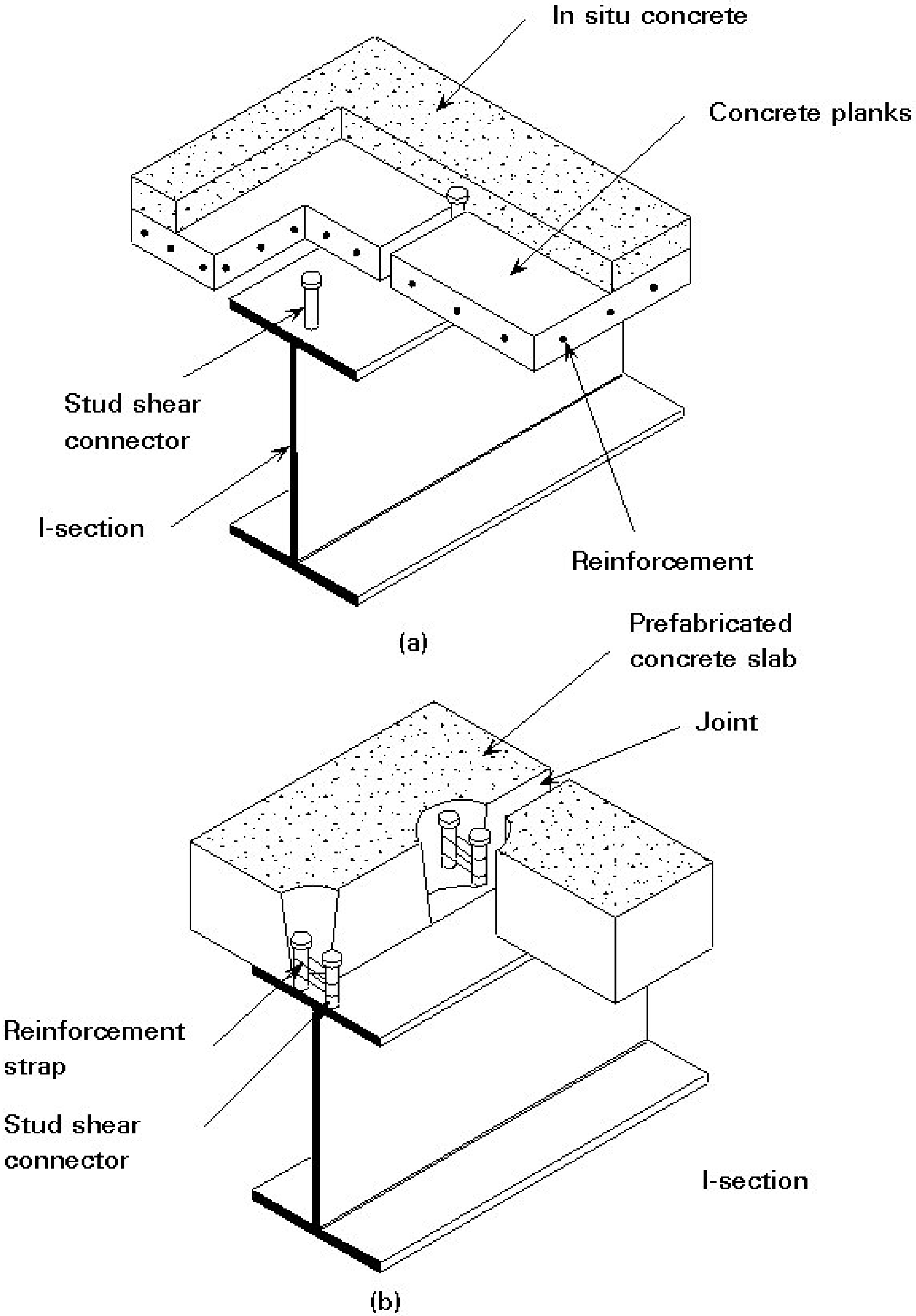
Impacts on the Schedule

Delivery, shakeout, and erection durations should not be impacted by the use of cambered beams

AISC.org

Structural Steel: The Material of Choice

Composite beam with prefab concrete slab



Composite Hollow-core Slabs

•

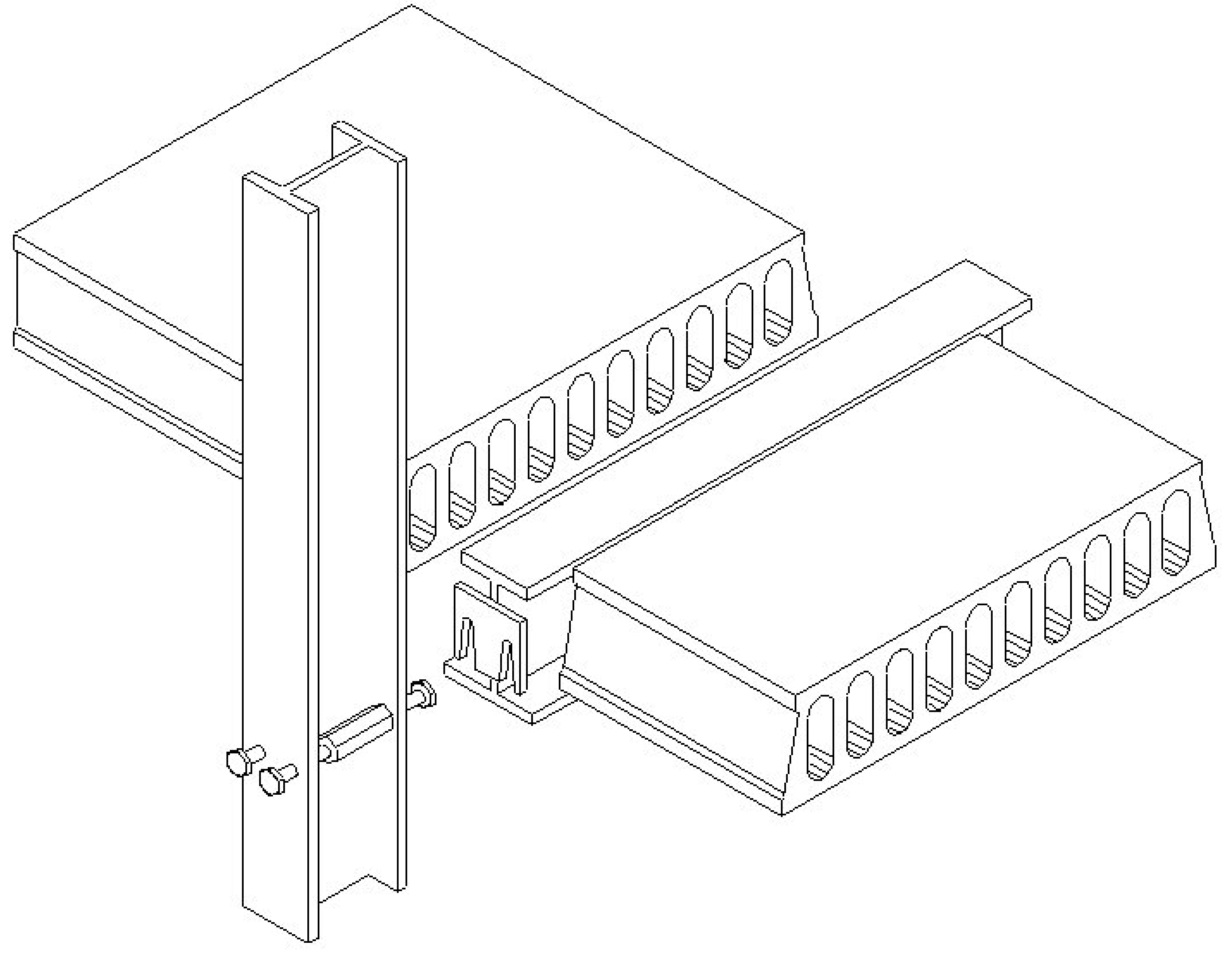


Figure 4 'Slim floor' system

Composite Hollow-core Slabs

•

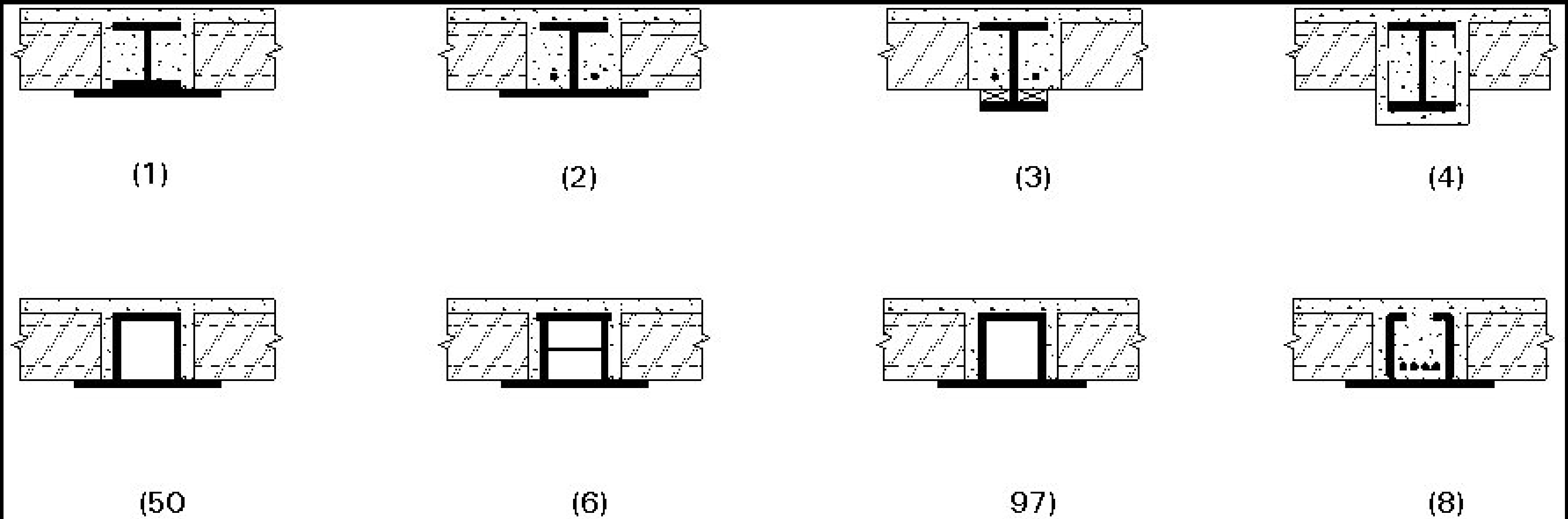


Figure 5b Integrated steel beams for 'slim floor' systems

Composite construction for fire resistance

-

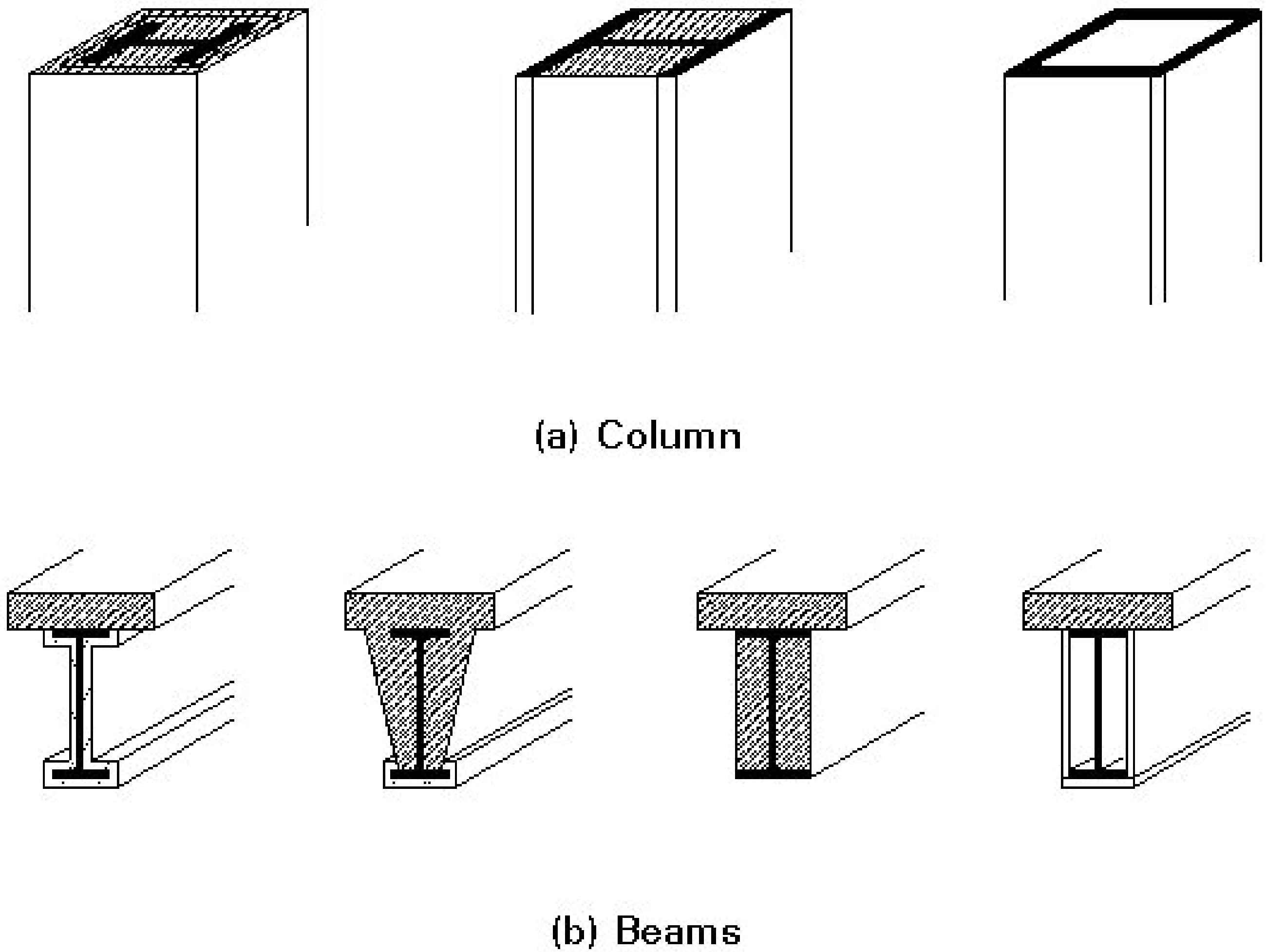


Figure 6 Typical solutions for fire protection

References

AISC. (1991). *Design Guide for Low- and Medium-Rise Steel Buildings.* American Institute of Steel Construction, Inc. Chicago, IL.

AISC. (1999). *Construction Management of Steel Construction*. American Institute of Steel Construction, Inc. Chicago, IL.

AISC. (2000). *Code of Standard Practice for Steel Buildings and Bridges.* American Institute of Steel Construction, Inc. Chicago, IL.

AISC. (2002). *Designing With Structural Steel – A Guide for Architects.* American Institute of Steel Construction, Inc. Chicago, IL .

AISC. (2003). *Design Guide for Serviceability Design Considerations for Steel Buildings, Second Edition.* American Institute of Steel Construction, Inc. Chicago, IL.

AISC Digital Library (2008)

Allen, E. (1999). *Fundamentals of Building Construction Materials and Methods.* John Wiley & Sons, Inc. New York, NY.

ASCE. (2002). "Construction Considerations for Composite Steel-and-Concrete Floor Systems." *Journal of Structural Engineering*, Vol. 128, No. 9, 1099-1110.

American Welding Society, (AWS). (2004). "Structural Welding Code – Section 7: Stud Welding." *ANSI/AWS D1.1-98,* Miami, FL.

References Cont.

ESDEP-the European Steel Design Education Programme - lectures

Larson, J. W., and Huzzard, R. K. (1990). “Economical Use of Cambered Steel Beams.” *Proc. AISC Engineering Conference*, Chicago, IL. 3-21.

Means, R.S. (2004). *2004 Building Construction Cost Data.* R.S. Means Company, Inc., Kingston, MA.

Occupational Safety & Health Administration, (OSHA). (1996). “Concrete and Masonry Construction.” Available at: http://www.osha.gov/doc/outreachtraining/htmlfiles/concrete.html. Viewed June, 2004.

Ricker, Jr., D. T. (1989) . “Cambering Steel Beams.” *AISC Engineering Journal,* 4, 136-142.

Richard Lees Steel Decking, (RLSD). (2002). “Composite Beams & Shear Studs – Information Sheet CB5.” Richard Lees Steel Decking. Available at: http://www.rlsd.com/. Viewed April, 2004.

Ruddy, J. L. (1986). “Ponding of Concrete Deck Floors.” *AISC Engineering Journal,* 3, 107-115.

Steel Inspection News, (SIN). (1993). “Shear Connector Inspection – a Tutorial.” Steel Structures Technology Center, Inc. Available at: http://www.steelstructures.com/StlInspNews/NEWS%20index.htm. Viewed April, 2004.